US00RE48081E

(19) **United States**
(12) **Reissued Patent**
Donohue

(10) **Patent Number: US RE48,081 E**
(45) **Date of Reissued Patent: Jul. 7, 2020**

(54) **VENTURI VALVE AND CONTROL SYSTEM**

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(21) Appl. No.: **15/692,195**

(22) Filed: **Aug. 31, 2017**

Related U.S. Patent Documents

Reissue of:
(64) Patent No.: **9,255,721**
Issued: **Feb. 9, 2016**
Appl. No.: **13/415,690**
Filed: **Mar. 8, 2012**

(51) **Int. Cl.**
F16K 31/12 (2006.01)
F24F 11/74 (2018.01)
F24F 11/00 (2018.01)
F24F 110/40 (2018.01)

(52) **U.S. Cl.**
CPC ***F24F 11/74*** (2018.01); *F24F 2110/40* (2018.01); *Y10T 137/7789* (2015.04)

(58) **Field of Classification Search**
CPC F24F 11/74; F24F 2110/40; F24F 11/04; F24F 2011/0042; Y10T 137/7789; G01F 1/36; G01F 1/40; G01F 1/44; G01F 1/46
See application file for complete search history.

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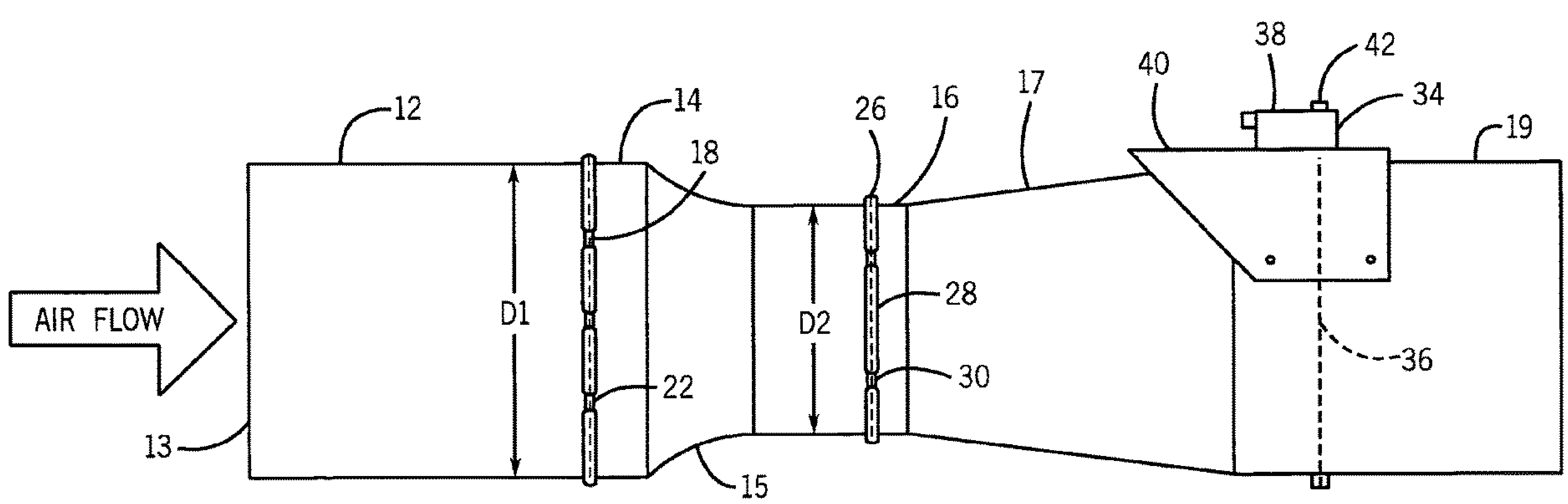
(74) *Attorney, Agent, or Firm* — Donald J. Ersler

(57) **ABSTRACT**

Embodiments of the invention provide a venturi valve and control system for use in an indoor environment to regulate air flow. The venturi valve includes a substantially cylindrical pipe, a high pressure sensing assembly, a low pressure sensing assembly, a differential pressure transducer, and a damper assembly. The high pressure sensing assembly and the low pressure sensing assembly do not substantially impede air flow through the valve. A controller is connected to the differential pressure transducer and a damper actuator. The controller determines a current flow rate of air into the indoor environment and operates the damper actuator in order to provide a desired flow rate of air into the indoor environment.

13 Claims, 15 Drawing Sheets



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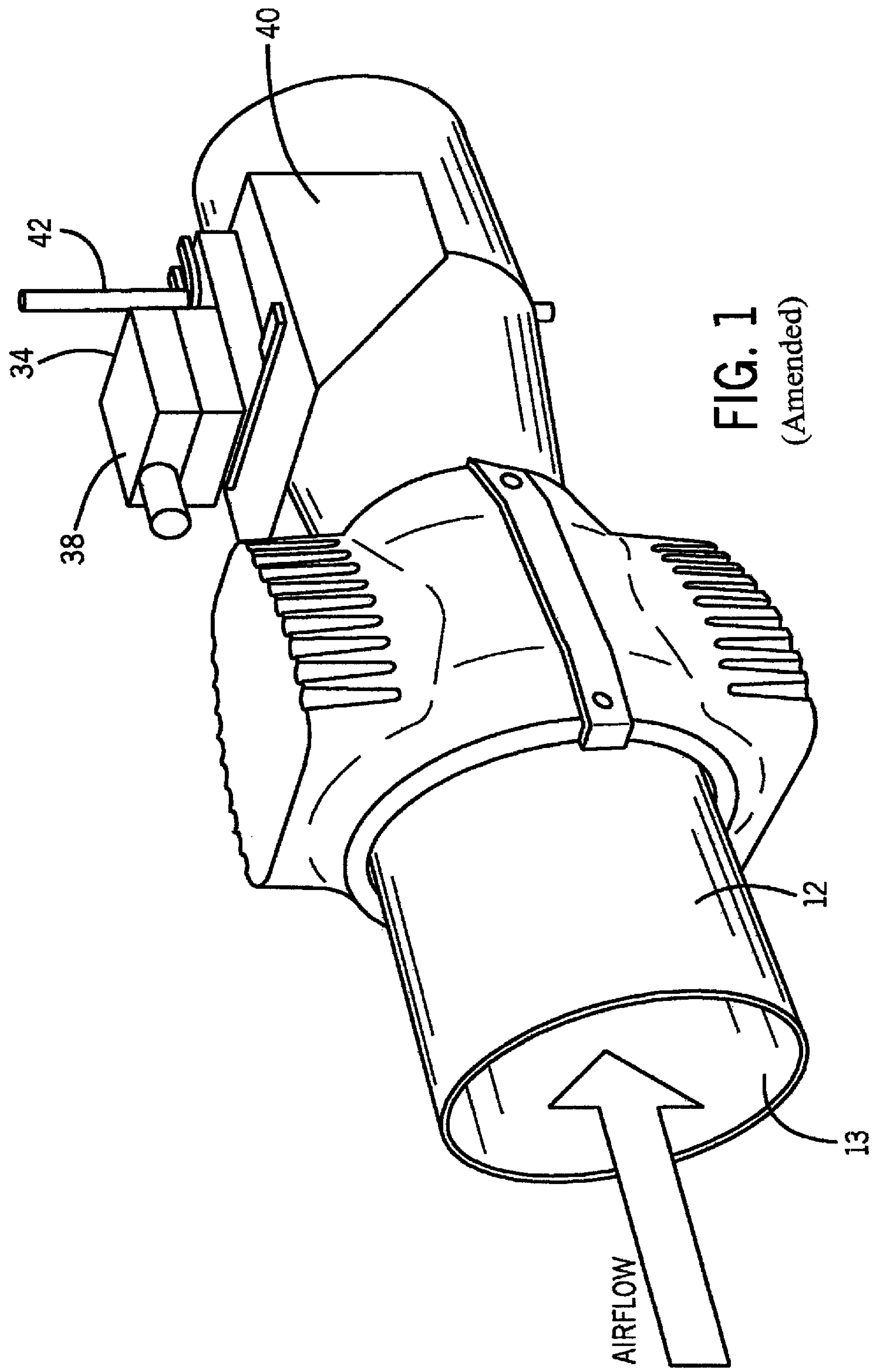


FIG. 1
(Amended)

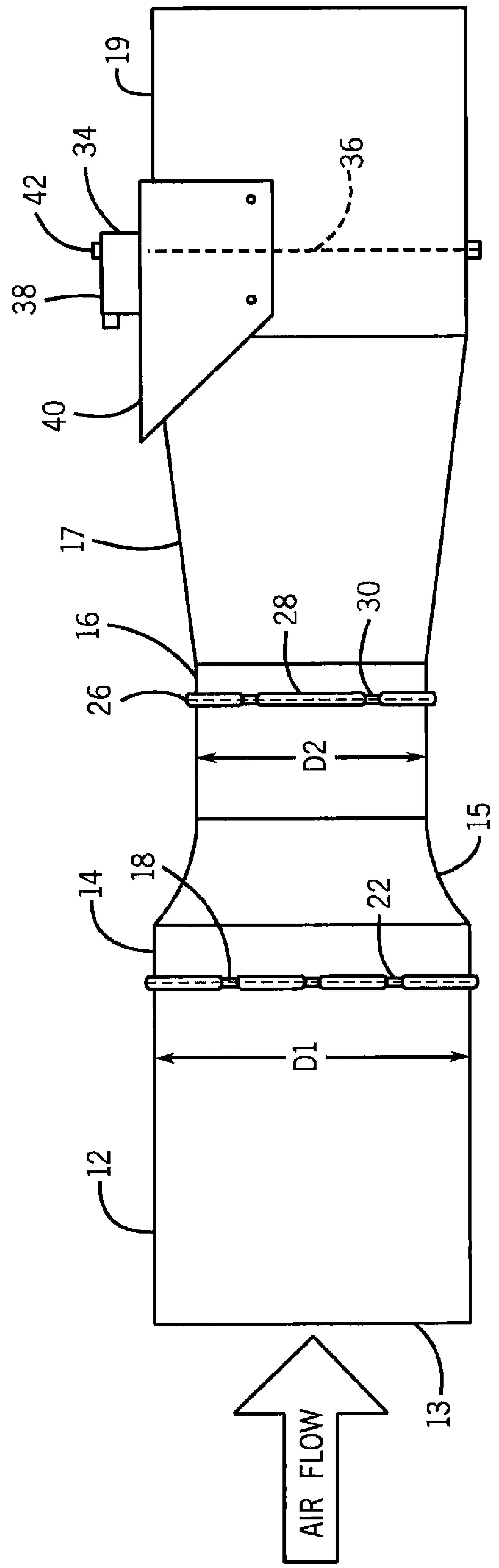

19
34
42
36
38
40
17
16
28
30
26
D2
15
14
18
22
D1
12
13
AIR FLOW

FIG. 2

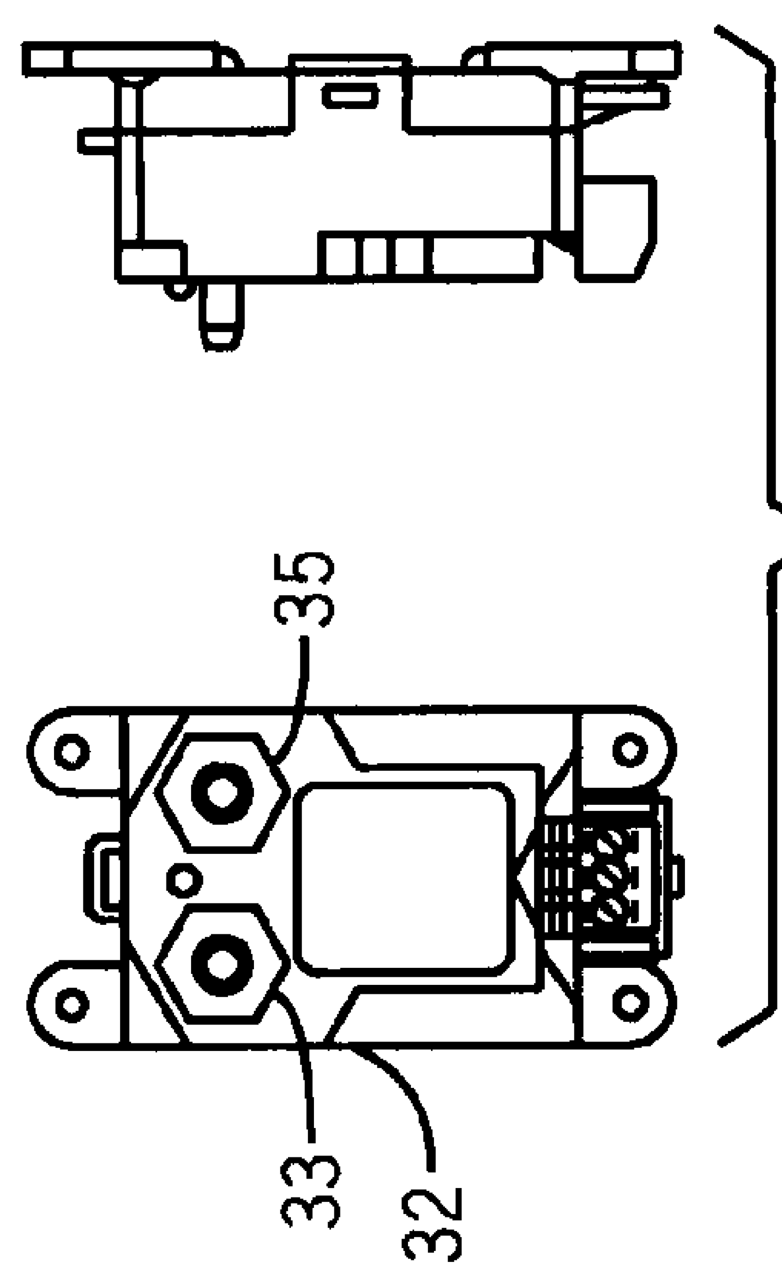

35
33
32

FIG. 3

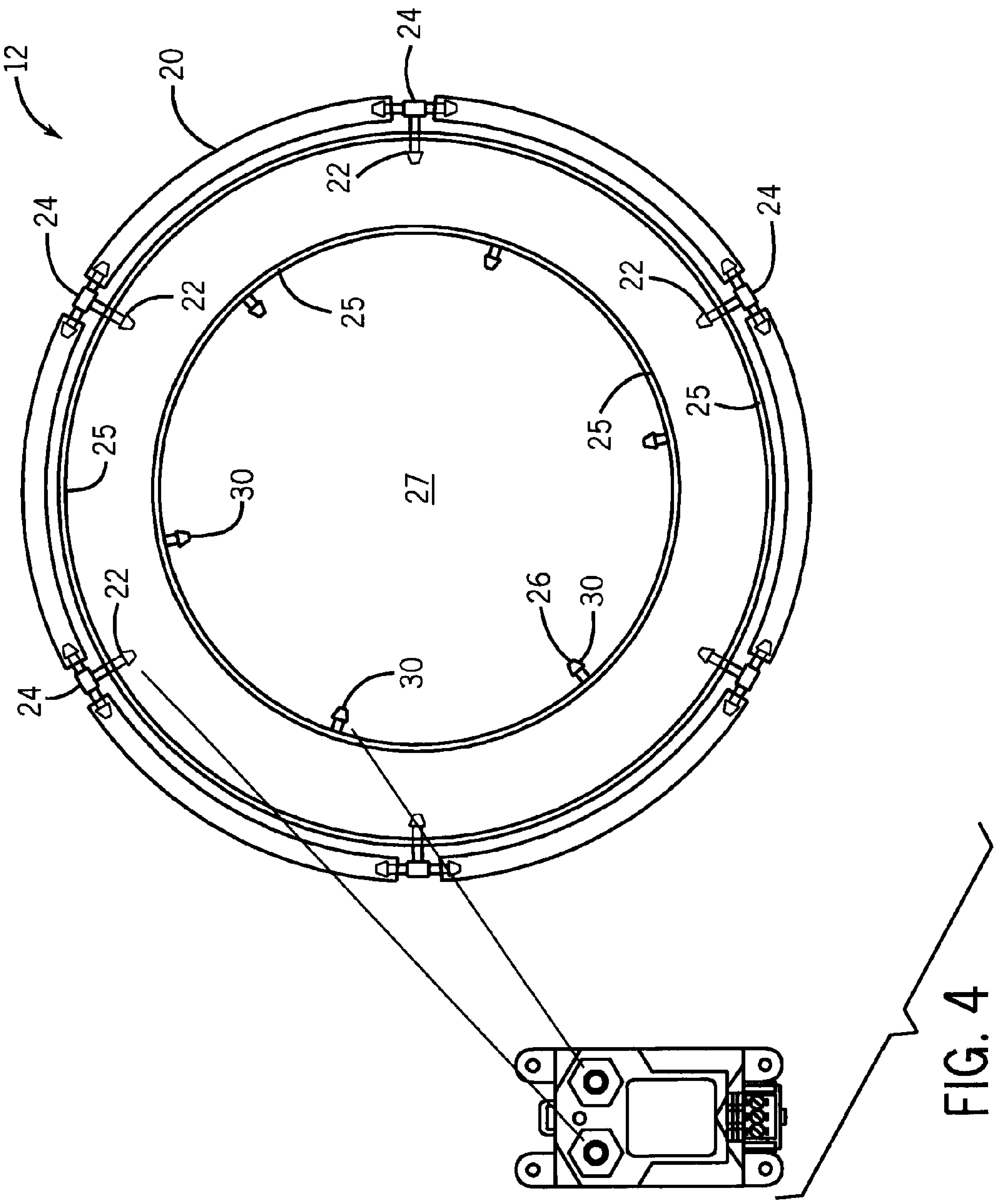


FIG. 4

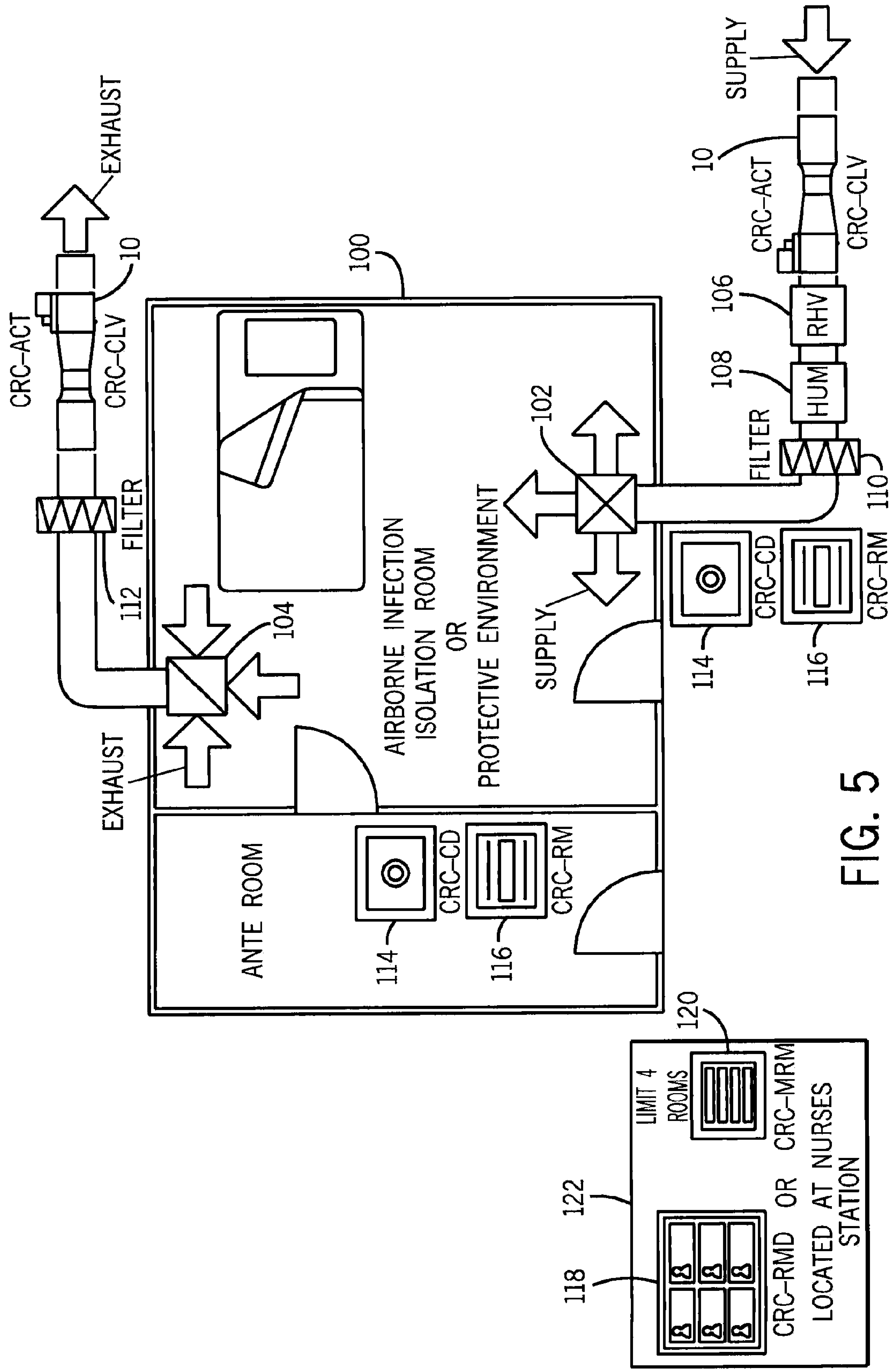

EXHAUST
10
CRC–ACT
CRC–CLV
FILTER
112
104
EXHAUST
100
AIRBORNE INFECTION
ISOLATION ROOM
OR
PROTECTIVE ENVIRONMENT
SUPPLY
102
ANTE ROOM
CRC–CD
CRC–RM
114
116
SUPPLY
10
CRC–ACT
CRC–CLV
106
RHV
108
HUM
FILTER
110
CRC–CD
CRC–RM
114
116
120
LIMIT 4
ROOMS
CRC–MRM
122
118
CRC–RMD OR
LOCATED AT NURSES
STATION

FIG. 5

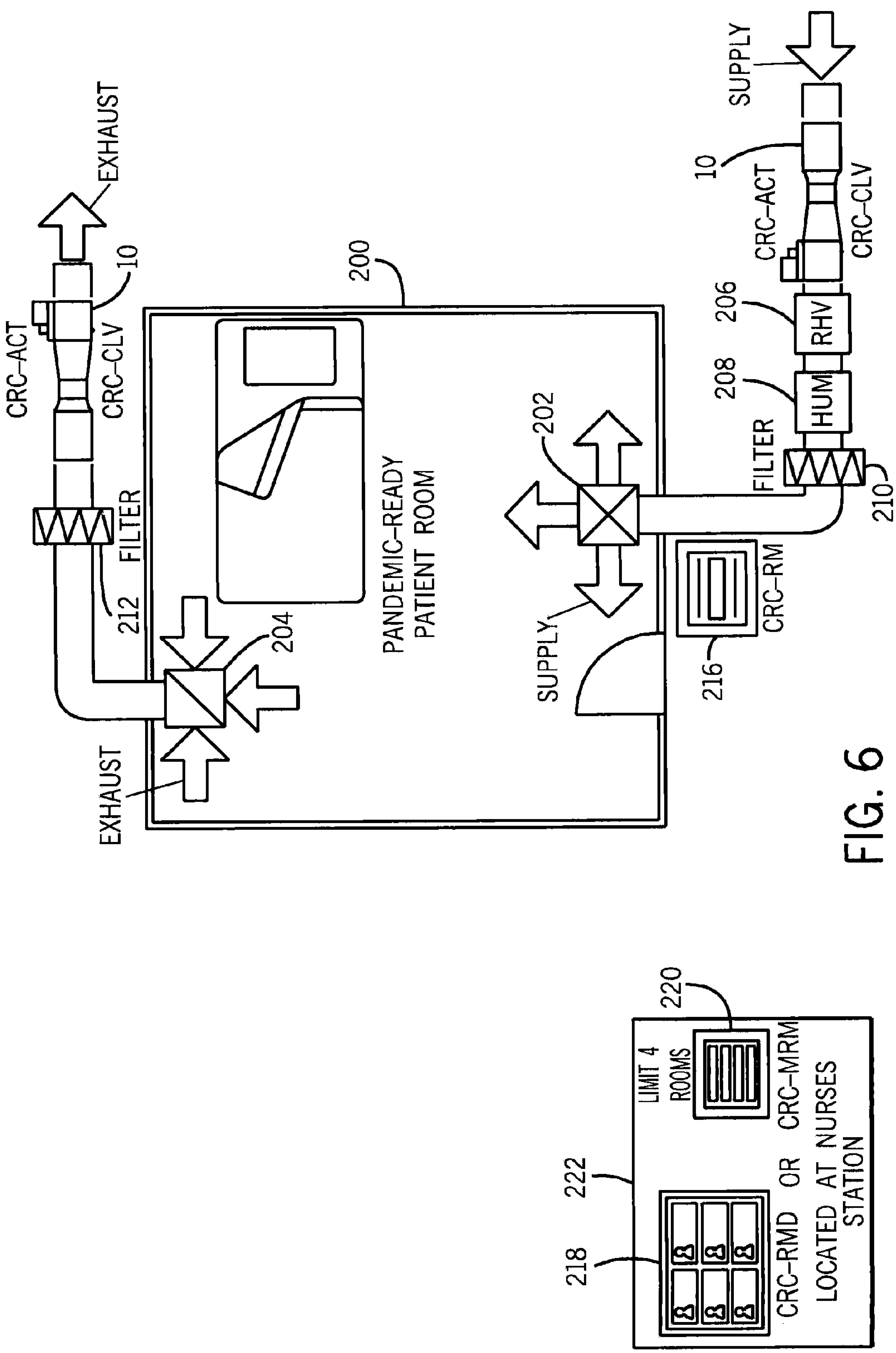

EXHAUST
CRC–ACT
CRC–CLV
10
FILTER
212
204
EXHAUST
200
PANDEMIC–READY
PATIENT ROOM
202
SUPPLY
216
CRC–RM
SUPPLY
10
CRC–ACT
CRC–CLV
206
RHV
208
HUM
FILTER
210
218
222
220
LIMIT 4
ROOMS
CRC–RMD OR CRC–MRM
LOCATED AT NURSES
STATION

FIG. 6

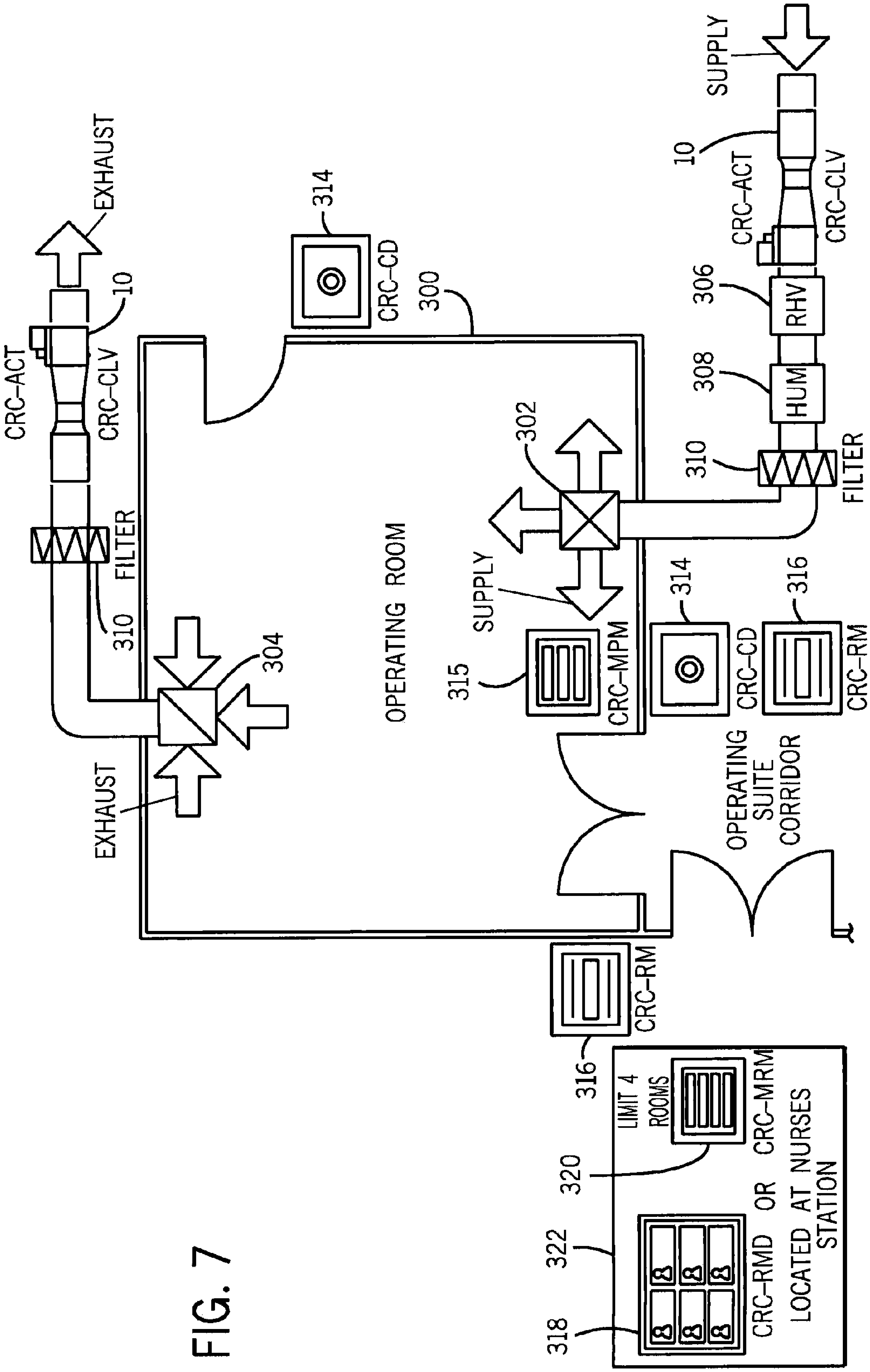

EXHAUST
10
CRC–ACT
CRC–CLV
FILTER
310
304
EXHAUST
314
CRC–CD
300
OPERATING ROOM
SUPPLY
302
315
CRC–MPM
314
CRC–CD
316
CRC–RM
OPERATING SUITE CORRIDOR
SUPPLY
10
CRC–ACT
CRC–CLV
306
RHV
308
HUM
310
FILTER
CRC–RM
316
LIMIT 4 ROOMS
CRC–MRM
320
322
318
CRC–RMD OR
LOCATED AT NURSES STATION

FIG. 7

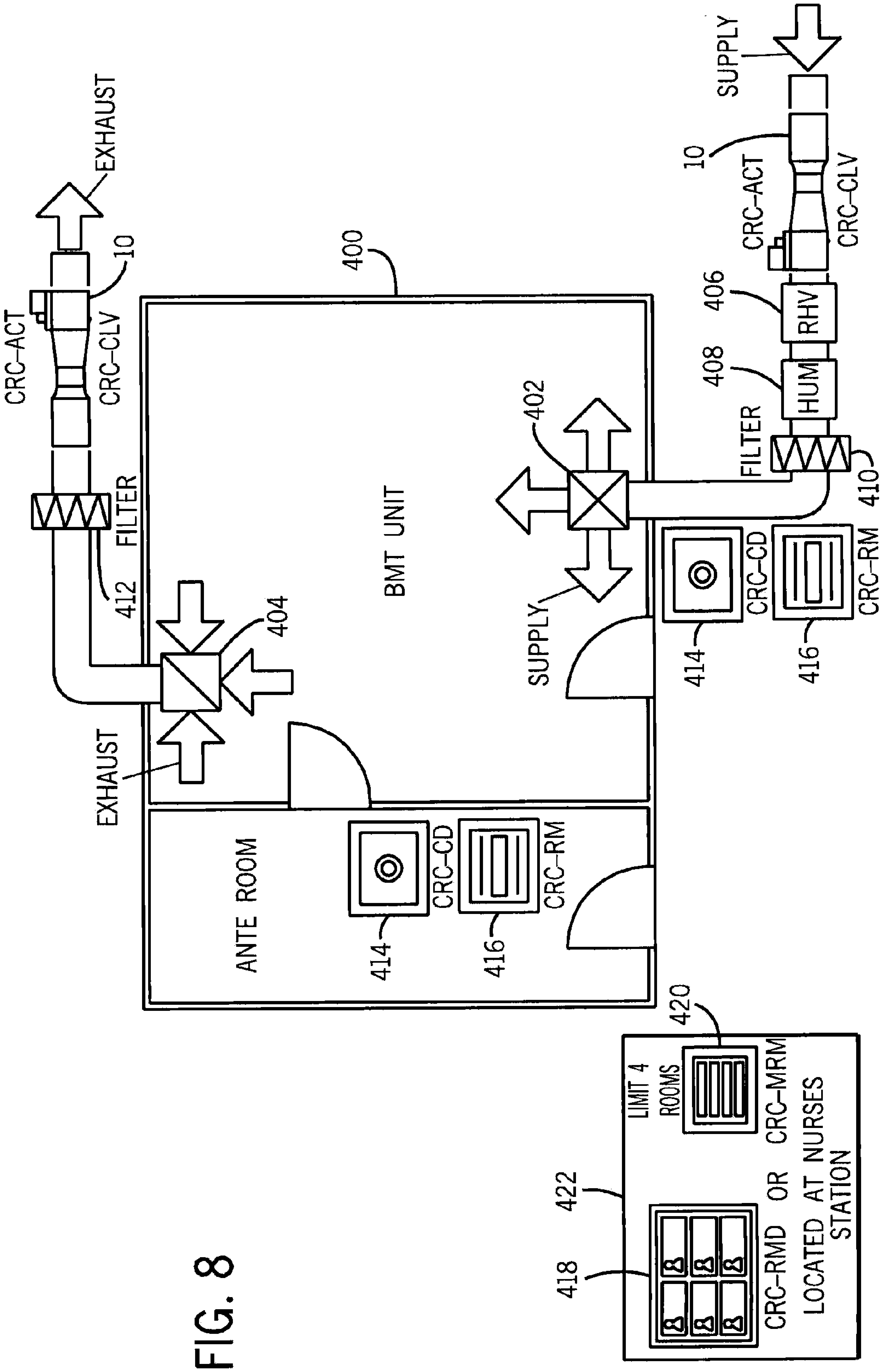

EXHAUST
10
CRC-ACT
CRC-CLV
FILTER
412
404
EXHAUST
400
BMT UNIT
402
SUPPLY
SUPPLY
10
CRC-ACT
CRC-CLV
406
RHV
408
HUM
FILTER
410
CRC-CD
CRC-RM
414
416
ANTE ROOM
CRC-CD
CRC-RM
414
416
420
LIMIT 4 ROOMS
CRC-MRM
422
418
CRC-RMD OR
LOCATED AT NURSES STATION

FIG. 8

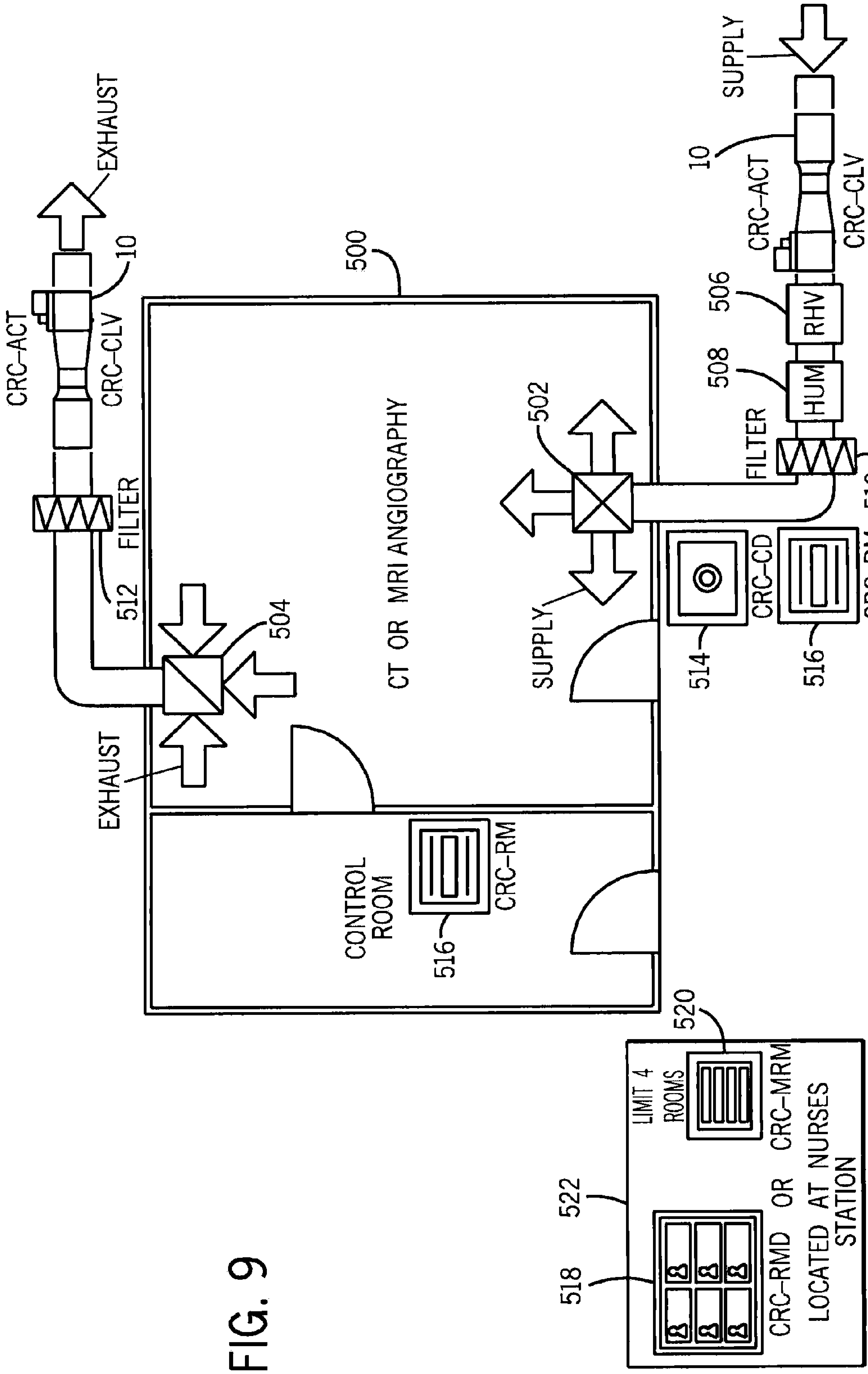

EXHAUST
10
CRC–ACT
CRC–CLV
FILTER
512
504
EXHAUST
500
CT OR MRI ANGIOGRAPHY
502
SUPPLY
CONTROL ROOM
CRC–RM
516
SUPPLY
10
CRC–ACT
CRC–CLV
506
RHV
508
HUM
FILTER
510
CRC–CD
514
CRC–RM
516
520
LIMIT 4 ROOMS
CRC–MRM
522
518
CRC–RMD OR CRC–MRM
LOCATED AT NURSES STATION

FIG. 9

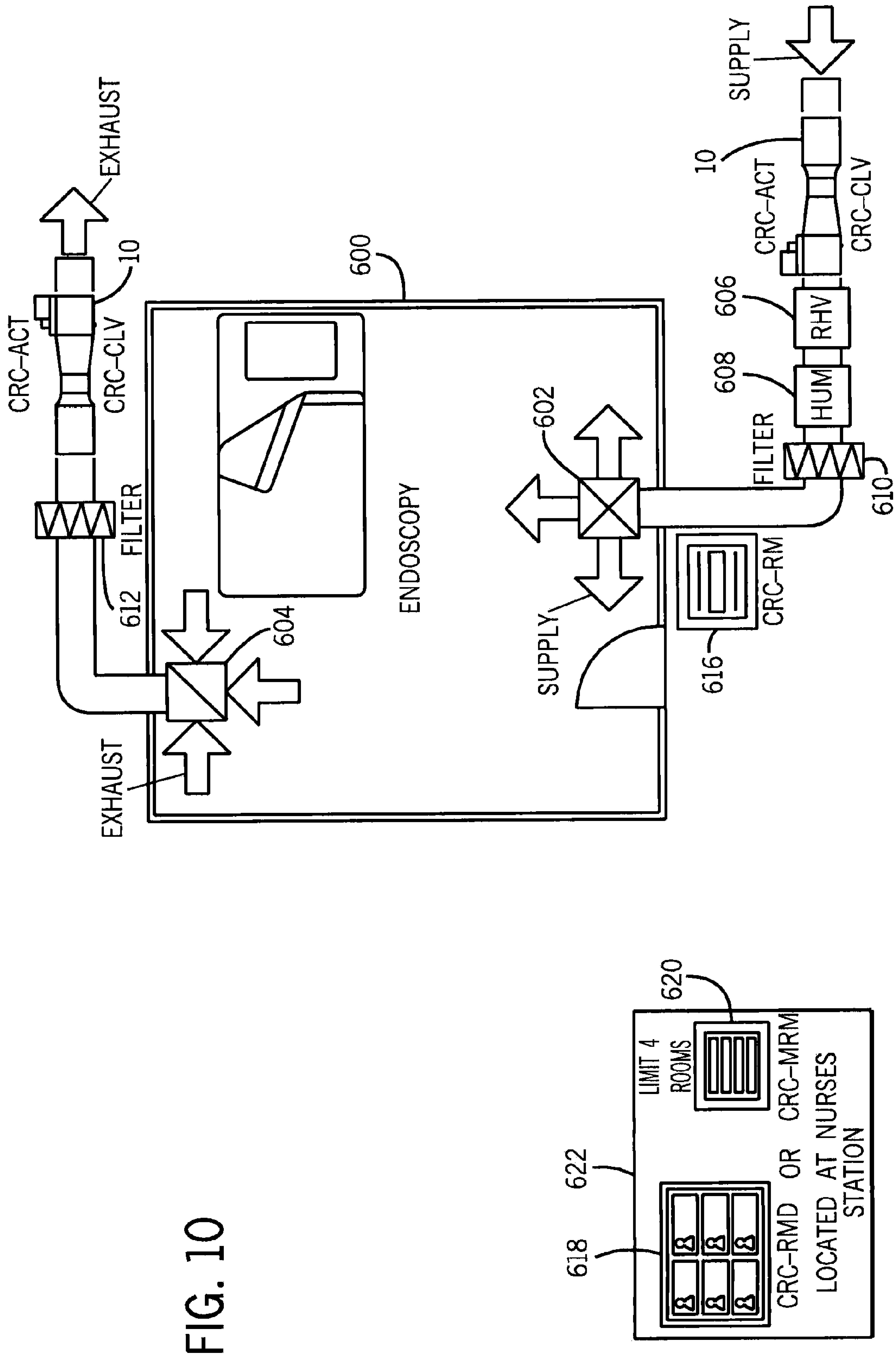
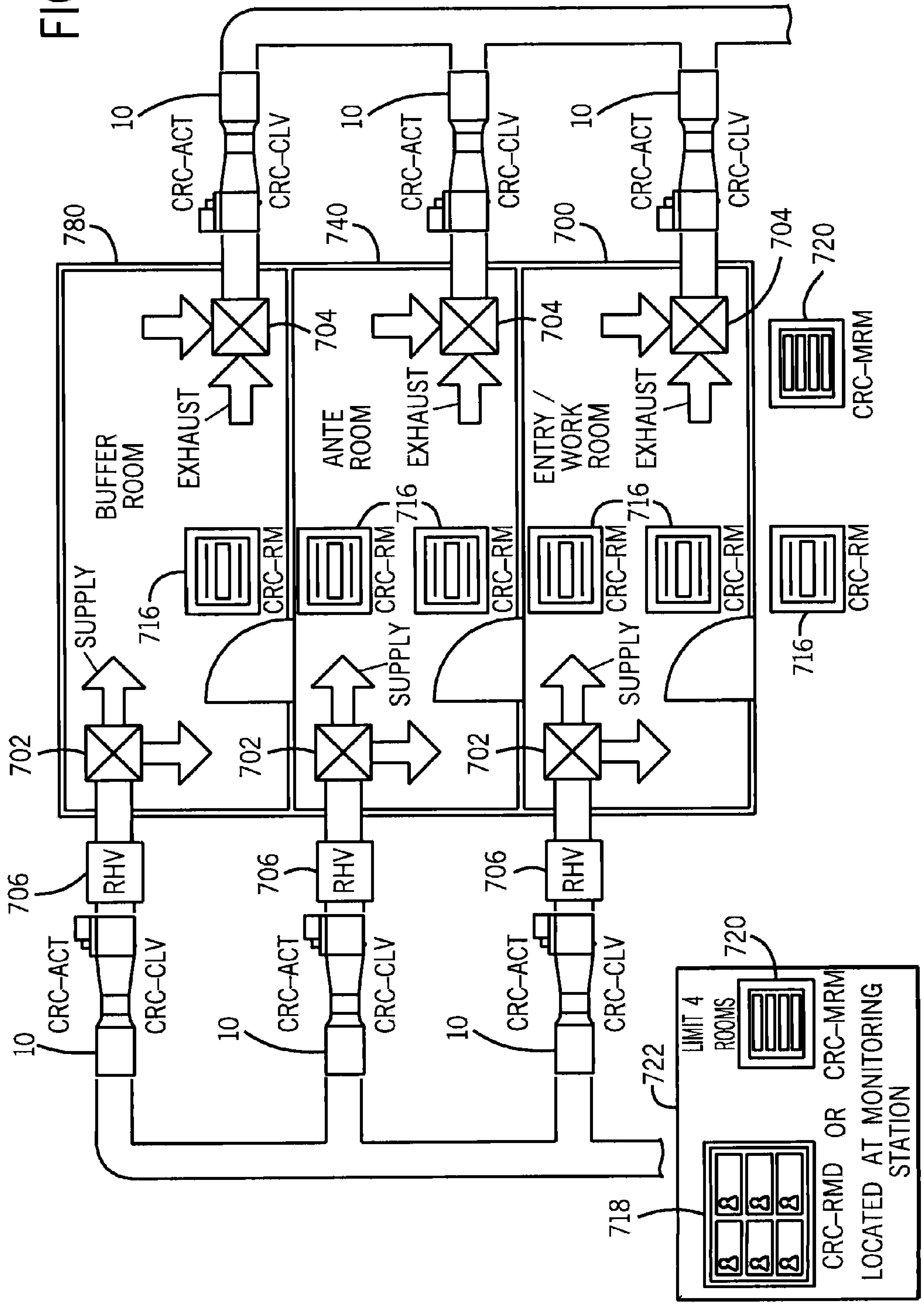

EXHAUST
CRC–ACT
CRC–CLV
10
FILTER
612
604
EXHAUST
600
ENDOSCOPY
602
SUPPLY
CRC–RM
616
SUPPLY
10
CRC–ACT
CRC–CLV
606
RHV
608
HUM
FILTER
610
620
LIMIT 4
ROOMS
CRC–MRM
622
618
CRC–RMD OR
LOCATED AT NURSES
STATION

FIG. 10

FIG. 11



10
CRC–ACT
CRC–CLV
780
740
700
704
720
CRC–MRM
BUFFER ROOM
ANTE ROOM
ENTRY / WORK ROOM
EXHAUST
SUPPLY
716
CRC–RM
702
706
RHV
722
LIMIT 4 ROOMS
718
CRC–RMD OR CRC–MRM
LOCATED AT MONITORING STATION

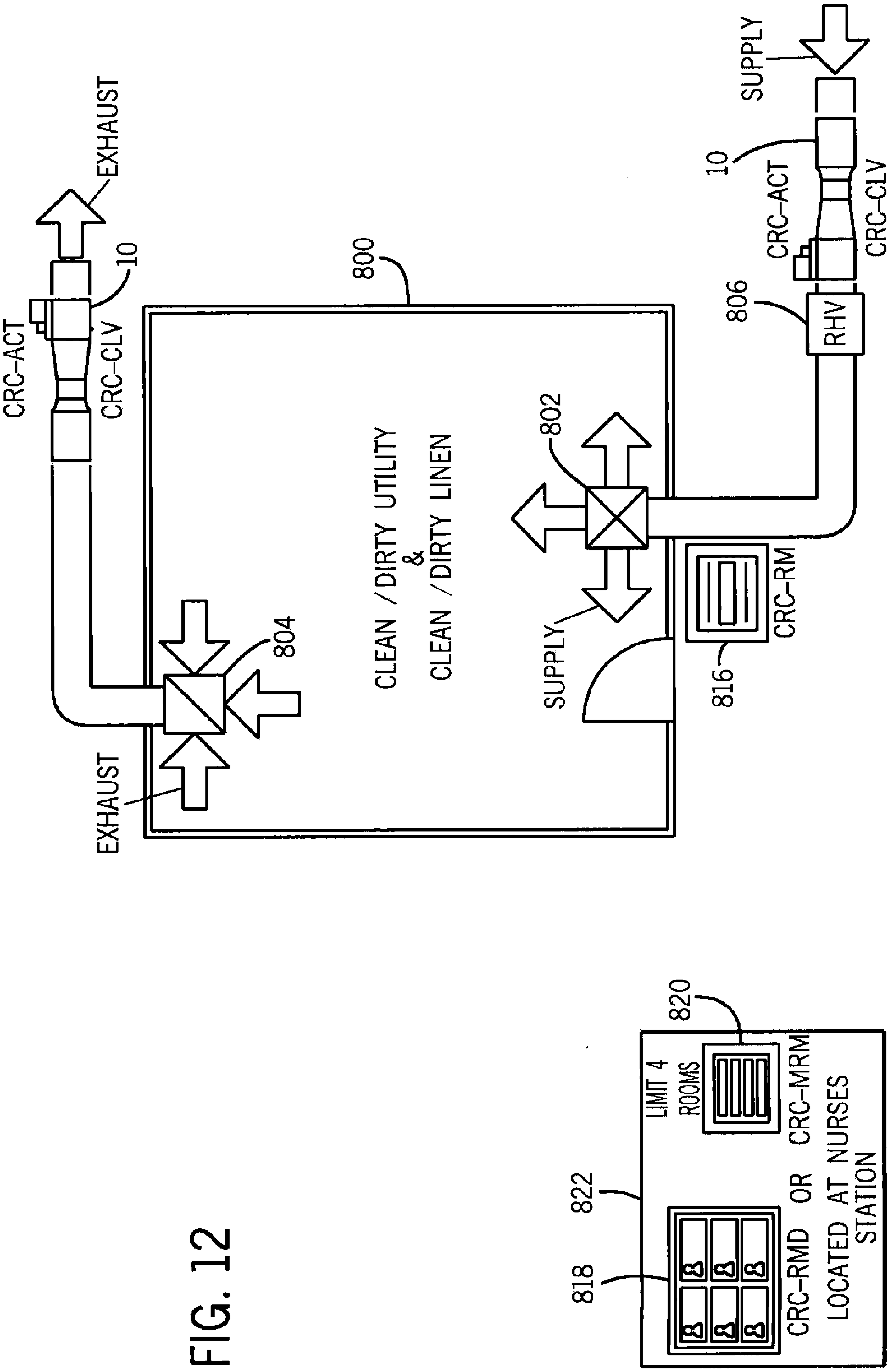

EXHAUST
CRC-ACT
CRC-CLV
10
800
SUPPLY
10
CRC-ACT
CRC-CLV
806
RHV
802
CLEAN / DIRTY UTILITY
&
CLEAN / DIRTY LINEN
804
SUPPLY
CRC-RM
816
EXHAUST
820
LIMIT 4
ROOMS
CRC-MRM
822
818
CRC-RMD OR CRC-MRM
LOCATED AT NURSES
STATION

FIG. 12

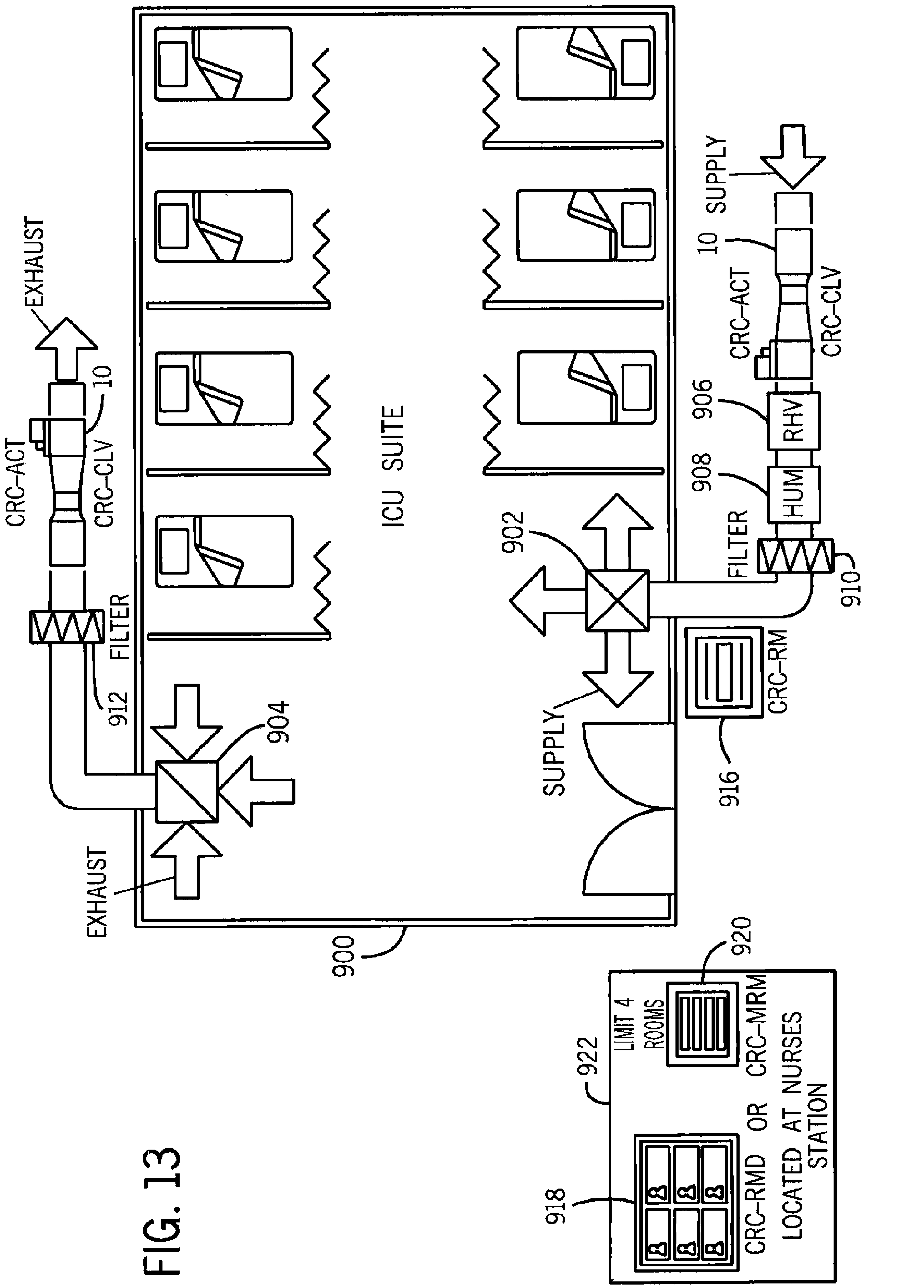
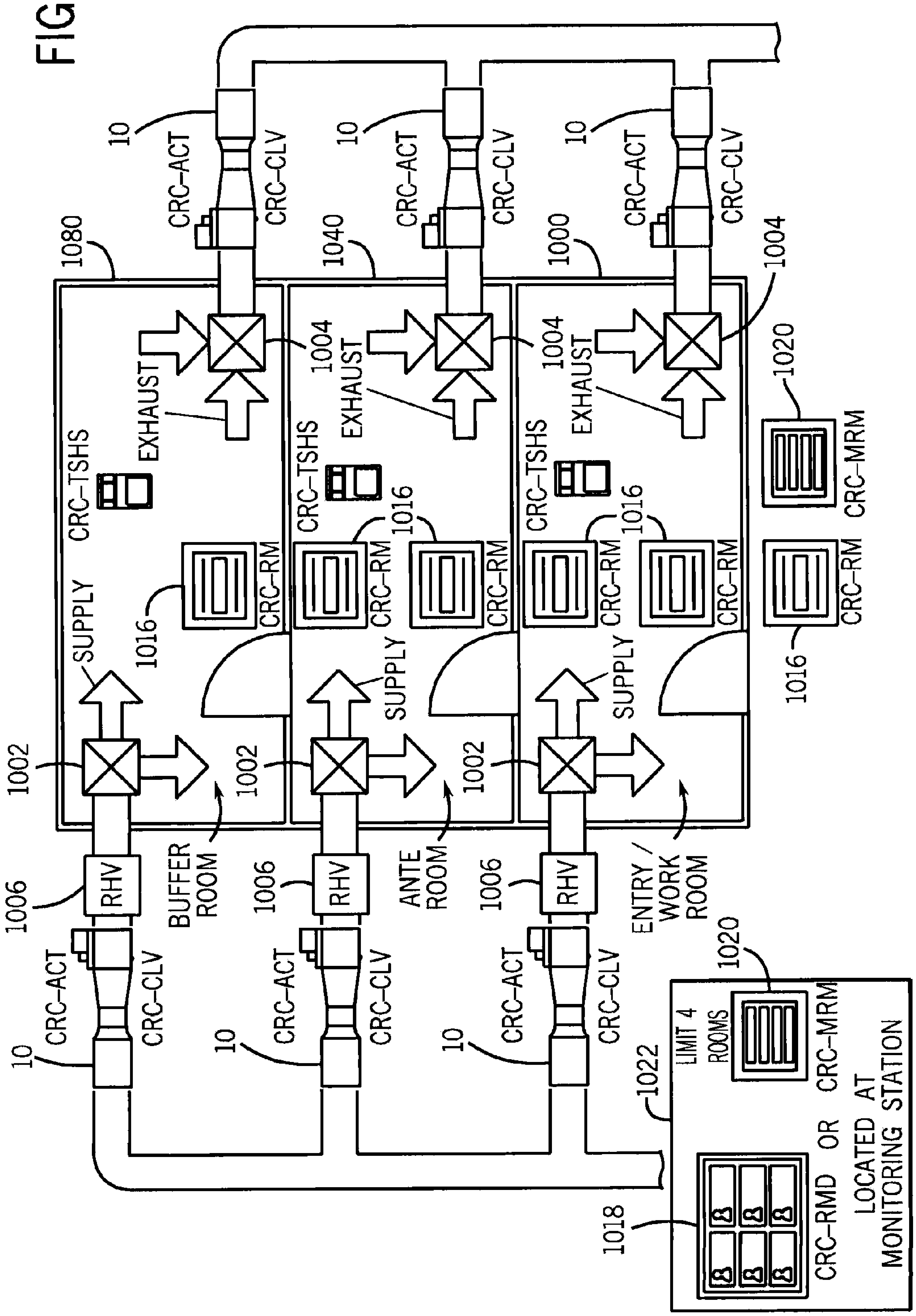

ICU SUITE
EXHAUST
10
CRC-ACT
CRC-CLV
FILTER
912
904
EXHAUST
900
902
SUPPLY
CRC-RM
916
FILTER
910
908
HUM
906
RHV
CRC-ACT
CRC-CLV
10
SUPPLY
918
922
920
LIMIT 4 ROOMS
CRC-RMD OR CRC-MRM
LOCATED AT NURSES STATION

FIG. 13

FIG. 14


10
CRC–ACT
CRC–CLV
1080
1040
1000
1004
EXHAUST
CRC–TSHS
1016
CRC–RM
1020
CRC–MRM
SUPPLY
1002
1006
RHV
BUFFER ROOM
ANTE ROOM
ENTRY / WORK ROOM
1022
LIMIT 4 ROOMS
1018
CRC–RMD OR CRC–MRM
LOCATED AT MONITORING STATION

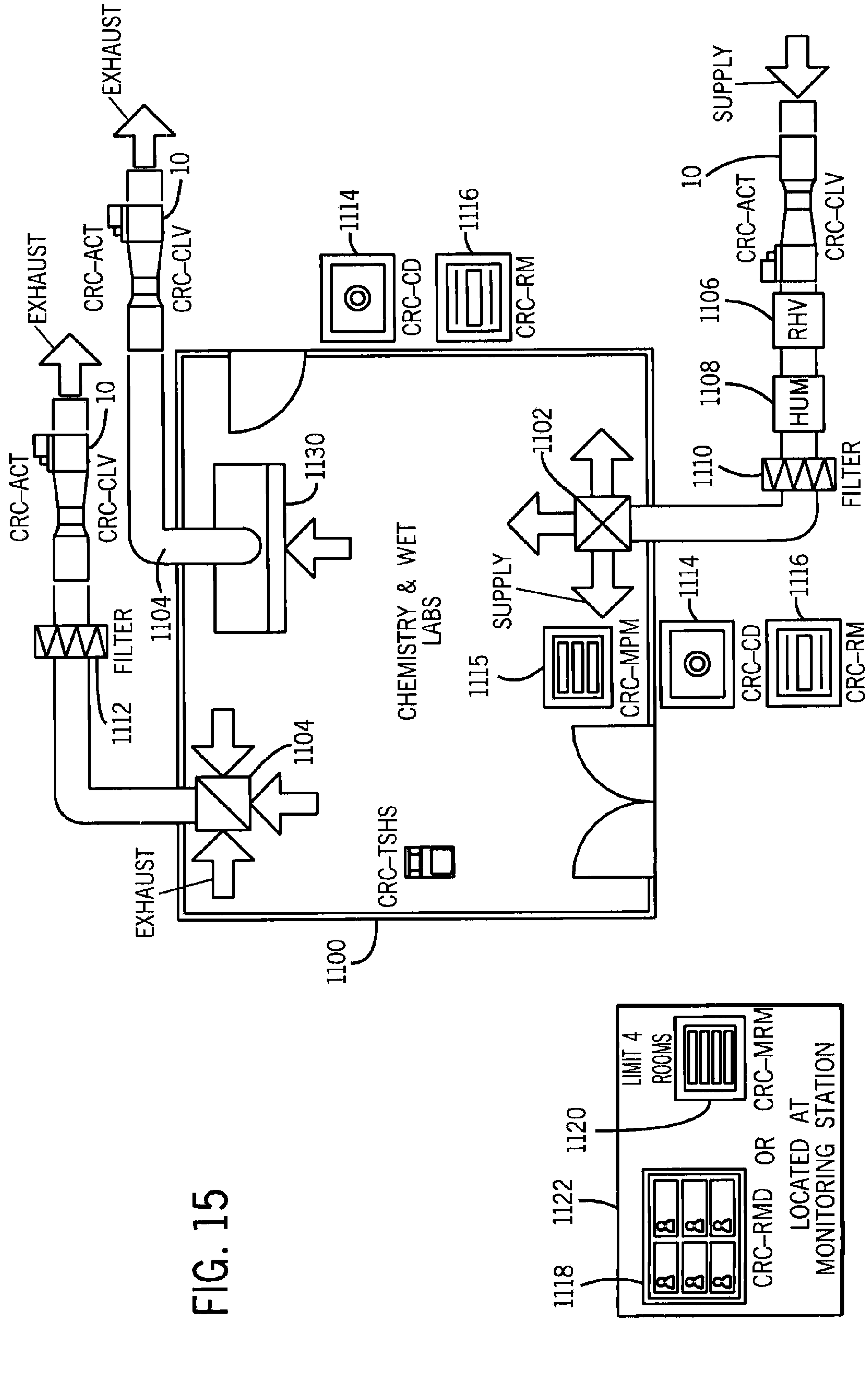

EXHAUST
EXHAUST
CRC-ACT
CRC-CLV
10
FILTER
1112
1104
1130
1114
CRC-CD
1116
CRC-RM
CHEMISTRY & WET LABS
SUPPLY
1102
1115
CRC-MPM
CRC-TSHS
1100
SUPPLY
RHV
1106
HUM
1108
1110
LIMIT 4 ROOMS
1120
CRC-MRM
1122
1118
CRC-RMD OR
LOCATED AT MONITORING STATION

FIG. 15

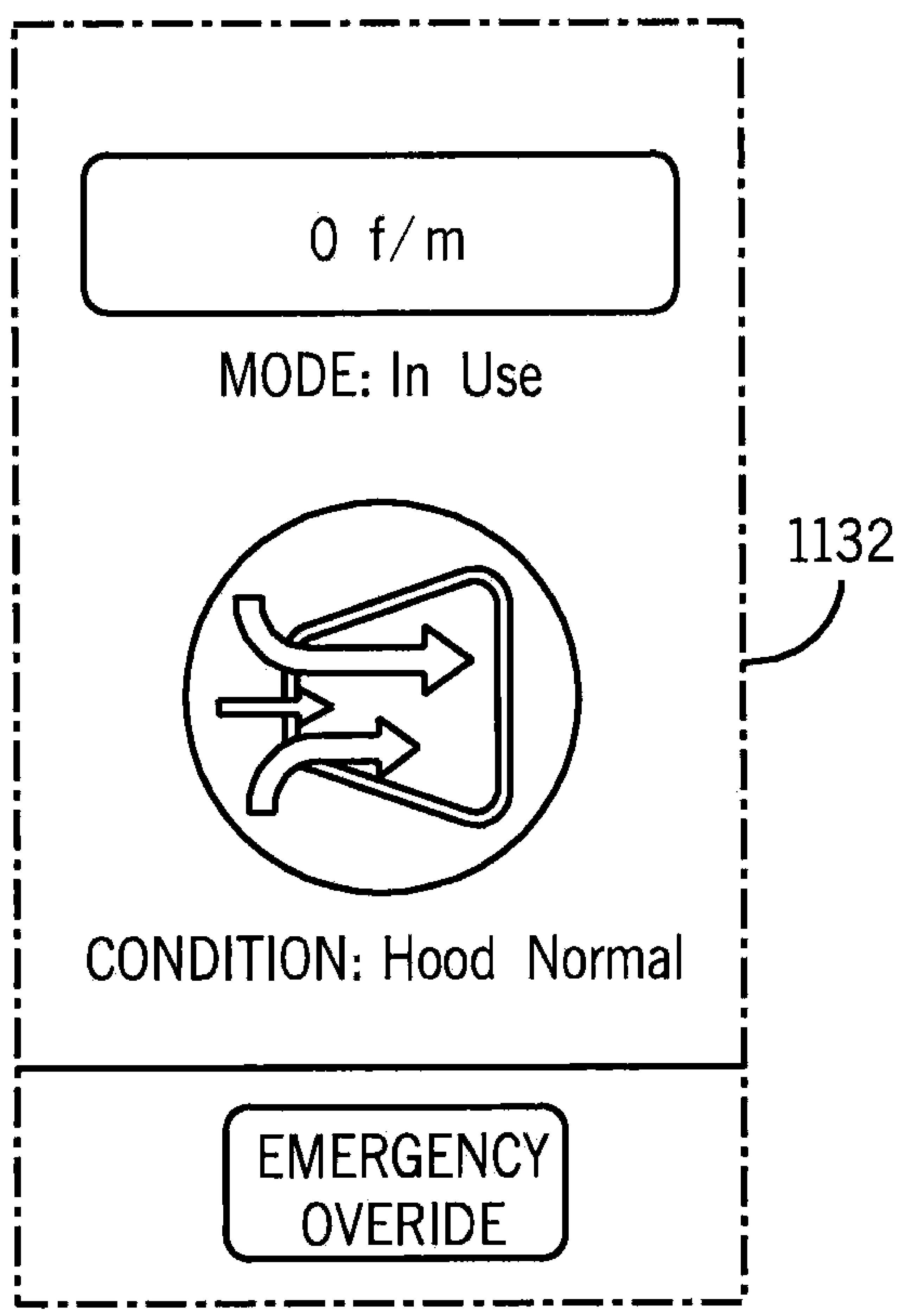

0 f/m
MODE: In Use
CONDITION: Hood Normal
1132
EMERGENCY OVERIDE

FIG. 16

VENTURI VALVE AND CONTROL SYSTEM

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

BACKGROUND

There are many applications where a valve is provided in an air flow path to control the flow of the air, for example, in the ducting of an indoor critical environment (hospitals, laboratories, etc.) or in the ducting of an indoor non-critical environment (classrooms, conference rooms, etc.). Some conventional valves include an air flow station in the form of a cross flow sensor that includes two cross bars to measure total pressure and static pressure in order to determine the velocity pressure inside the valve. The velocity pressure is used to calculate the current air flow rate, and a damper inside the valve is rotated to provide the desired air flow rate.

Other conventional valves include a mechanical air regulator in the form of a cone-shaped element positioned in and movable in the valve's orifice. The cone-shaped element varies the size of an annular-shaped fluid flow path formed in the orifice. Due to the shape of the cone and the orifice, the pressure drop across the valve's orifice can be measured by the force exerted on the cone by the difference between the static pressure directly in front of and behind the cone caused by the increased air velocity behind the cone. The valve uses this force to act upon a variable rate spring located inside the cone, which connects the cone to the valve's shaft. The purpose of the spring is to provide a pressure-compensating action so that for a given position of the valve's shaft, the flow rate of the valve is constant or independent of pressure changes over some range of pressure drops across the valve. However, the actual air flow rate is derived from the position of the valve's shaft, not from sensor measurements of the static pressure in front of and behind the cone.

In both of these conventional configurations there is an air flow station or mechanical air regulator positioned inside the valve's orifice that interferes with a significant portion of the cross-sectional area available for air flow. When the air flow station or mechanical air regulator interferes with air flow, the air flow station and even the valve itself can become clogged with debris. In addition, both the cross flow sensor and the cone-spring configurations must be calibrated properly in order to accurately determine the actual air flow rate. If these devices are no longer calibrated properly, the valve must be accessed within the walls of the building to re-calibrate it.

SUMMARY

In light of the problems set forth above, there is a need for a valve for use in indoor environments that does not include an air flow station or mechanical air regulator that interferes with air flow.

Some embodiments of the invention provide a venturi valve for use in an indoor environment to regulate air flow. The venturi valve can include a substantially cylindrical pipe including a first section having a first diameter and a second section having a second diameter, with the first diameter

being larger than the second diameter. The venturi valve can include a high pressure sensing assembly with a first pneumatic tube positioned around the first diameter. The first pneumatic tube can be coupled to several air inlet ports. The air inlet ports can be spaced around the first diameter to sense a first average static pressure at the first diameter. The venturi valve can include a low pressure sensing assembly with a second pneumatic tube positioned around the second diameter. The second pneumatic tube can also be coupled to several air inlet ports. The air inlet ports can be spaced around the second diameter to sense a second average static pressure at the second diameter.

The venturi valve can also include a differential pressure transducer coupled to the high pressure sensing assembly and the low pressure sensing assembly. The differential pressure transducer can generate a differential pressure signal based on the first average static pressure and the second average static pressure. In addition, the venturi valve can include a damper assembly coupled to the substantially cylindrical pipe. The damper assembly can include a damper and a damper actuator. A controller can be connected to the differential pressure transducer and the damper actuator. The controller can determine a current flow rate of air into the indoor environment based on a differential pressure signal. The controller can operate the damper actuator based on the current flow rate in order to provide a desired flow rate of air into the indoor environment.

Embodiments of the invention also provide a system for controlling air flow through an indoor environment including a supply duct and an exhaust duct. The system can include a first venturi valve adapted to be coupled to the supply duct. The first venturi valve includes a first differential pressure transducer to generate a first differential pressure signal. The first venturi valve is capable of measuring air flow in the supply duct without substantially impeding air flow. The system also includes a second venturi valve adapted to be coupled to the exhaust duct. The second venturi valve includes a second differential pressure transducer to generate a second differential pressure signal. The second venturi valve is capable of measuring air flow in the exhaust duct without substantially impeding air flow. The system further includes a room monitor connected to the first differential pressure transducer and the second differential pressure transducer and a room management display connected to the room monitor.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a venturi valve according to one embodiment of the invention.

FIG. **2** is a side view of the venturi valve of FIG. **1**.

FIG. **3** is a front view of a differential pressure transducer of the venturi valve of FIG. **1**.

FIG. **4** is an end view of the venturi valve of FIG. **1**.

FIG. **5** is a schematic illustration of the venturi valve of FIG. **1** for use in an airborne infection isolation room.

FIG. **6** is a schematic illustration of the venturi valve of FIG. **1** for use in a pandemic-ready patient room.

FIG. **7** is a schematic illustration of the venturi valve of FIG. **1** for use in an operating room.

FIG. **8** a schematic illustration of the venturi valve of FIG. **1** for use in a bone marrow transplant unit.

FIG. **9** is a schematic illustration of the venturi valve of FIG. **1** for use in a medical imaging room.

FIG. **10** is a schematic illustration of the venturi valve of FIG. **1** for use in an another medical imaging room.

FIG. **11** is a schematic illustration of the venturi valve of FIG. **1** for use in a pharmacy or oncology/hematology room.

FIG. **12** is a schematic illustration of the venturi valve of FIG. **1** for use in a utility or linen room.

FIG. **13** is a schematic illustration of the venturi valve of FIG. **1** for use in an intensive care unit suite.

FIG. **14** is a schematic illustration of the venturi valve of FIG. **1** for use in a biosafety level laboratory or containment suite.

FIG. **15** is a schematic illustration of the venturi valve of FIG. **1** for use in a chemistry and wet laboratory.

FIG. **16** is a schematic illustration of a fume hood controller for use with the venturi valve of FIG. **1**.

DETAILED DESCRIPTION

Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof herein is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. Unless specified or limited otherwise, the terms "mounted," "connected," "supported," and "coupled" and variations thereof are used broadly and encompass both direct and indirect mountings, connections, supports, and couplings. Further, "connected" and "coupled" are not restricted to physical or mechanical connections or couplings.

The following discussion is presented to enable a person skilled in the art to make and use embodiments of the invention. Various modifications to the illustrated embodiments will be readily apparent to those skilled in the art, and the generic principles herein can be applied to other embodiments and applications without departing from embodiments of the invention. Thus, embodiments of the invention are not intended to be limited to embodiments shown, but are to be accorded the widest scope consistent with the principles and features disclosed herein. The following detailed description is to be read with reference to the figures, in which like elements in different figures have like reference numerals. The figures, which are not necessarily to scale, depict selected embodiments and are not intended to limit the scope of embodiments of the invention. Skilled artisans will recognize the examples provided herein have many useful alternatives and fall within the scope of embodiments of the invention.

FIG. **1** illustrates a venturi valve **10** according to one embodiment of the invention. The venturi valve **10** can be used in an indoor environment, such as a critical or non-critical environment, to regulate air flow. For example, the venturi valve **10** can be used in critical environments such as a health care facility, a patient room, an isolation room, a procedure room, a pharmacy, an oncology room, a laboratory, an operating room, a research facility, a wet chemistry laboratory, a bio-containment room, a clean room, a life science facility, a vivarium, an open bench laboratory. The venturi valve **10** can also be used in non-critical environments such as a commercial space, an office space, a data room, a conference room, a government facility, a university space, a classroom, and a lecture hall.

As shown in FIG. **2**, the venturi valve **10** includes a substantially cylindrical pipe **12** with a venturi inlet **13**, a first section **14** having a first diameter D**1**, and a second section **16** having a second diameter D**2**. The first diameter D**1** is larger than the second diameter D**2**. As also shown in FIG. **2**, the pipe **12** can include additional sections having varying diameters between the first diameter D**1** and the second diameter D**2**. For example, the pipe **12** can include a reducing diameter at a third section **15** and a gradually increasing diameter at a fourth section **17**. In some embodiments, the diameter at a fifth section **19** downstream of the fourth section **17** can be substantially equal to the first diameter D**1**. In one embodiment, the pipe **12** can be constructed of 0.080" aluminum or 0.040" stainless steel.

The venturi valve **10** includes a high pressure sensing assembly **18** with a first pneumatic tube **20** positioned around the first diameter D**1**. As shown in FIG. **4**, the first pneumatic tube **20** is coupled to several air inlet ports **22**. The air inlet ports **22** can include T-shaped connectors **24** in order to connect several segments together to make up the pneumatic tube **20** extending around the first diameter D**1**. The air inlet ports **22** are spaced (e.g., equally spaced) around the first diameter D**1** in order to sense a first average static pressure at the first diameter D**1**. In some embodiments, at least six air inlet ports **22** are positioned around the first diameter D**1**. As shown in FIG. **4**, the air inlet ports **22** are coupled to an internal surface **25** of the pipe **12**. The air inlet ports **22** extend only minimally into an internal portion **27** of the pipe **12** in order to not interfere with air flow. In some embodiments, the air inlet ports **22** do not extend into the internal portion **27** of the pipe **12**, but rather are surface flush with the pipe **12**. In other embodiments, the air inlet ports **22** can extend about one-quarter of an inch, about one-eighth of an inch, or up to about two inches into the internal portion **27** of the pipe **12**. In this manner, the air inlet ports **22** do not block the pipe **12** so that they are non-obstructive across the duct created by the pipe **12** and include no moving parts in the air stream. In other words, the air inlet ports **22** do not substantially impede air flow through the pipe **12** or bisect the pipe **12**. As a result of there being no moving parts, the venturi valve **10** can be installed in any orientation as dictated by field requirements. In addition, there are no critical components located in the air stream.

The venturi valve **10** also includes a low pressure sensing assembly **26** including a second pneumatic tube **28** positioned around the second diameter D**2**. The second pneumatic tube **28** is coupled to several air inlet ports **30**. The air inlet ports **30** are spaced around the second diameter D**2** to sense a second average static pressure at the second diameter D**2**. In some embodiments, at least six air inlet ports **30** are positioned around the second diameter D**2**. The air inlet ports **30** can include T-shaped connectors in order to connect several segments together to make up the pneumatic tube **28** extending around the second diameter D**2**. The air inlet ports **30** are spaced (e.g., equally spaced) around the second diameter D**2** in order to sense a second average static pressure at the second diameter D**2**.

As shown in FIG. **3**, the venturi valve **10** can be incorporated with a differential pressure transducer **32** that is coupled to the high pressure sensing assembly **18** and the low pressure sensing assembly **26**. The differential pressure transducer **32** can include a high pressure connector **33** connected to the high pressure sensing assembly **18** and a low pressure connector **35** connected to the low pressure sensing assembly **26**. The differential pressure transducer **32** can generate a differential pressure signal based on the first average static pressure and the second average static pressure. The venturi valve **10** can measure the differential pressure across the venturi created by the pipe **12** having a first diameter D**1** and a second smaller diameter D**2**. In one embodiment, the differential pressure transducer **32** can be an ultra-low direct differential pressure transmitter with dead end technology incorporating a Si-Glas variable capacitance sensor and digital compensation with an application specific integrated circuit (ASIC). The differential pressure transducer **32** can include a diaphragm constructed of silicon without glues or organics that contribute to drift over time. The differential pressure transducer **32** can have an accuracy of 0.4% full scale. The differential pressure transducer **32** can include an integral LED light that increases intensity as the differential pressure increases.

As shown in FIG. **1**, the differential pressure transducer **32**, the high pressure sensing assembly **18**, and the low pressure sensing assembly **26** can be surrounded by a cover **33**. The cover **33** can include a two-piece housing and can incorporate a heat sink, in some embodiments.

As shown in FIGS. **1** and **2**, the venturi valve **10** can be incorporated with a damper assembly **34** coupled to pipe **12**. The damper assembly **34** can include a rotatable damper panel **36** (or a non-rotatable damper) and a damper actuator **38**. The damper assembly **34** can be coupled to the pipe **12** using an actuator mounting bracket **40**. The damper assembly **34** can include a damper shaft **42** coupled between the damper actuator **38** and the rotatable damper panel **36**. When the damper actuator **38** rotates the damper shaft **42**, the damper panel **36** rotates within the pipe **12** in order to alter the open area of the pipe **12** to either allow more air flow or less air flow. The damper assembly **34** can be low leakage and rated for less than one percent of maximum rated flow at 3" WC inlet static pressure. The damper assembly **34** can include self-lubricating Teflon bearings. The damper shaft **42** can be solid steel.

In one embodiment, the damper actuator **38** is microprocessor based with conditioned feedback and uses brushless DC technology. In one embodiment, the damper actuator **38** delivers a minimum of 35 inch-pounds or 5.6 Newton meters of torque rated voltage and can be set for a 2 to 10 VDC signal and field wired for 4 to 20 mA. In some embodiments, the damper actuator **38** can include an external clutch for manual adjustments. In some embodiments, the damper actuator **38** can include a position indicator and a control signal that is fully programmable. The venturi valve **10** and the damper actuator **38** can be configured for fail-safe operation during a loss of power.

The venturi valve **10** can be connected to one or more controllers, such as room monitors **116-1116** (as further described herein) or various other types of controllers and monitors. The controller can be connected to the differential pressure transducer **32** and the damper actuator **38**. The controller can determine a velocity pressure based on the differential pressure signal from the differential pressure transducer **32**. The controller can determine a current flow rate of air into the critical or non-critical environment based on the velocity pressure and a constant K. The square root of the differential pressure measured across the venturi is multiplied by a constant K to derive an air flow rate in cubic feet per minute (CFM). The controller can operate the damper actuator **38** based on the current flow rate in order to provide a desired flow rate of air into the critical or non-critical environment.

The venturi valve **10** control strategy can be a closed loop system that utilizes direct flow measurement. The air flow feedback is sent to the controller where it is compared to the desired system air flow set point. The controller compares actual measured flow with the air flow set point and generates an error representing the difference between the measured air flow and the desired air flow. The control loop responds to the system error by adjusting the damper panel **36**. In some embodiments, the controller uses proportional-integral-derivative (PID) closed loop control.

FIG. **5** is a schematic illustration of the venturi valve **10** of FIG. **1** for use in an airborne infection isolation room **100**. The airborne infection isolation room **100** includes a supply duct **102** and an exhaust duct **104**. The venturi valve **10** can also be used in return ducts and bypass ducts. A first venturi valve **10** can be positioned in the supply duct **102** along with a reheat valve **106**, a humidity sensor **108**, and a first filter **110**. A second venturi valve **10** can be positioned in the exhaust duct **104** along with a second filter **112**. The airborne infection isolation room **100** can be equipped with room condition displays **114** and room monitors **116**, which can be in communication with a room management display **118** or a multi-room monitor **120**, for example located at a nurses' station **122**.

In one embodiment, the reheat valve 106 can have a fixed range of 1000 ohms, an input voltage of 10.5-45 VDC, and an output of 4-20 mA. In one embodiment, the humidity sensor **108** can be an ultra fast response polymer capacitance sensor that is not affected by condensation, fog, high humidity, or contaminants. In one embodiment, the humidity sensor **108** can have a range 0-100% with an accuracy of about ±2%/±3% and a hysteresis of about ±1%.

In some embodiments, a room static pressure transmitter can be mounted to the ceiling or a wall in the room in which the venturi valve **10** is used. The room static pressure transmitter can include a sintered stainless steel muffler that filters out noise associated with air movements common with high air change rate applications. In some embodiments, a door contactor can be installed in the room in which the venturi valve **10** is used. The door contactor can include a hermetically-sealed magnetic reed switch.

In some embodiments, the filters **110**, **112** can be duct mounted with integral, factory-mounted pressure controllers. The filters **110**, **112** can be bag-in, bag-out type filters. A single filter housing can include an optional pre-filter and a high-capacity HEPA final filter. The filters **110**, **112** can include glass fiber media and aluminum separators, along with filter cell sides that are constructed of galvanized plated steel and fire resistant wood. The filters **110**, **112** can have an efficiency of at least about 99.97% when tested with thermally generated D.O.P. and can have an initial pressure drop of 1.44 inches W.G. at a rated air-flow of 1000 CFM per filter.

The filters **110**, **112** can include a pre-filter unit with a premium extended surface type in 4 inch depth with an efficiency of about 25-30 percent for ASHRAE Standard 52-76 test method. The filters **110**, **112** can be connected to a filter monitor for selecting and displaying filter loading parameters on the room monitor **116** and/or the room management display **118**.

The room condition display **114** can include a TFT/VGA screen with programmable information indicating room status. The room condition display **114** can indicate status with a change in colored background and associated owner-selected messages and graphics. In one embodiment, the background color of the room condition display **114** for the isolation room **100** can indicate three distinct room conditions: (1) Infectious Room (Red/owner graphics and message); (2) Room being Cleared (Amber/owner graphics and message); and (3) Room Cleared (Green/owner graphics and message). The operation of the isolation room **100** can be separated into three modes: (1) "Infectious Condition—authorized personnel only" (room is in a negative or positive adjustable pressure relative to adjacent spaces); (2) "Room being Cleared—Do not enter" (room is in a negative or positive adjustable pressure relative to adjacent spaces); and (3) "Room Clear" (room pressure is neutral relative to adjacent spaces).

The room monitors **116** can be capable of measuring the differential pressure between two individual spaces at various locations. Each room can have its own room monitor **116** capable of stand-alone operation. Each room monitor **116** is capable of both visual and audible alarms. Each room monitor **116** uses direct pressure measurement with industrial quality differential pressure transducer technology. The room monitor **116** can use closed-loop control and can monitor the associated room condition display **114** and the room management display **118**. The room monitor **116** can also monitor one or more of the following: a supply terminal, a supply terminal with reheat, an exhaust terminal, an exhaust unit, a room temperature sensor, a duct temperature sensor, a room humidity sensor, a duct humidity sensor, a door contactor, a HEPA filter unit, a pre-filter unit, and/or a filter monitor. The room monitor **116** can maintain a safe and comfortable negative/neutral or positive/neutral pressurized relative to the adjacent spaces.

The room management display **118** can be a complete management tool capable of displaying and accessing a single room or any combination of critical rooms. The room management display **118** can be an easy to navigate monitor for use in making adjustments to associated critical spaces. The room management display **118** can have custom graphic programming to meet any desired sequence of operation. In addition to programming, the room management display **118** can have hardware and software to support one or more of the following protocols: BACnet (ARC 156, MS/TP, and PTP), Modbus (RTU & ASCII), N@ Bus, and LonWorks (optional plug-in card used for Lon Works). The room management display **118** can also support BACnet/IP communications through an optional Ethernet Plug-on card, which can provide Internet pages to a standard Internet Browser package.

FIG. **6** is a schematic illustration of the venturi valve **10** of FIG. **1** for use in a pandemic-ready patient room **200**. The pandemic-ready patient room **200** includes a supply duct **202** and an exhaust duct **204**. A first venturi valve **10** can be positioned in the supply duct **202** along with a reheat valve **206**, a humidity sensor **208**, and a first filter **210**. A second venturi valve **10** can be positioned in the exhaust duct **204** along with a second filter **212**. The pandemic-ready patient room **200** can be equipped with a room monitor **216**, which can be in communication with a room management display **218** or a multi-room monitor **220**, for example located at a nurses' station **222**.

FIG. **7** is a schematic illustration of the venturi valve **10** of FIG. **1** for use in an operating room **300**. The operating room **300** includes a supply duct **302** and an exhaust duct **304**. A first venturi valve **10** can be positioned in the supply duct **302** along with a reheat valve **306**, a humidity sensor **308**, and a first filter **310**. A second venturi valve **10** can be positioned in the exhaust duct **304** along with a second filter **312**. The operating room **300** can be equipped with room condition displays **314**, a multi-point monitor **315**, and room monitors **316**, which can be in communication with a room management display **318** or a multi-room monitor **320**, for example located at a nurses' station **322**.

FIG. **8** a schematic illustration of the venturi valve **10** of FIG. **1** for use in a bone marrow transplant unit. The bone marrow transplant unit **400** includes a supply duct **402** and an exhaust duct **404**. A first venturi valve **10** can be positioned in the supply duct **402** along with a reheat valve **406**, a humidity sensor **408**, and a first filter **410**. A second venturi valve **10** can be positioned in the exhaust duct **404** along with a second filter **412**. The bone marrow transplant unit **400** can be equipped with room condition displays **414** and room monitors **416**, which can be in communication with a room management display **418** or a multi-room monitor **420**, for example located at a nurses' station **422**.

FIG. **9** is a schematic illustration of the venturi valve **10** of FIG. **1** for use in a medical imaging room **500** for use with CT, MRI, or angiography equipment. The medical imaging room **500** includes a supply duct **502** and an exhaust duct **504**. A first venturi valve **10** can be positioned in the supply duct **502** along with a reheat valve **506**, a humidity sensor **508**, and a first filter **510**. A second venturi valve **10** can be positioned in the exhaust duct **504** along with a second filter **512**. The medical imaging room **500** can be equipped with a room condition display **514** and room monitors **516**, which can be in communication with a room management display **518** or a multi-room monitor **520**, for example located at a nurses' station **522**.

FIG. **10** is a schematic illustration of the venturi valve **10** of FIG. **1** for use in an anther medical imaging room **600** for use with endoscopy equipment. The medical imaging room **600** includes a supply duct **602** and an exhaust duct **604**. A first venturi valve **10** can be positioned in the supply duct **602** along with a reheat valve **606**, a humidity sensor **608**, and a first filter **610**. A second venturi valve **10** can be positioned in the exhaust duct **604** along with a second filter **612**. The medical imaging room **600** can be equipped with a room monitor **616**, which can be in communication with a room management display **618** or a multi-room monitor **620**, for example located at a nurses' station **622**.

FIG. **11** is a schematic illustration of the venturi valve of FIG. **1** for use in pharmacy or oncology/hematology rooms **700**, **740**, **780**. The pharmacy or oncology/hematology rooms **700**, **740**, **780** include supply ducts **702** and exhaust ducts **704**. First venturi valves **10** can be positioned in the supply ducts **702** along with reheat valves **706**. Second venturi valves **10** can be positioned in the exhaust ducts **704**. The pharmacy or oncology/hematology rooms **700**, **740**, **780** can be equipped with room monitor **716**, which can be in communication with a room management display **718** or multi-room monitors **720**, for example located at a monitoring station **722**.

FIG. **12** is a schematic illustration of the venturi valve of FIG. **1** for use in a utility or linen room **800**. The utility or linen room **800** includes a supply duct **802** and an exhaust duct **804**. A first venturi valve **10** can be positioned in the supply duct **802** along with a reheat valve **806**. A second venturi valve **10** can be positioned in the exhaust duct **804**. The utility or linen room **800** can be equipped with a room monitor **816**, which can be in communication with a room management display **818** or a multi-room monitor **820**, for example located at a nurses' station **22**.

FIG. **13** is a schematic illustration of the venturi valve of FIG. **1** for use in an intensive care unit (ICU) suite **900**. The ICU suite **900** includes a supply duct **902** and an exhaust duct **904**. A first venturi valve **10** can be positioned in the supply duct **902** along with a reheat valve **906**, a humidity sensor **908**, and a first filter **910**. A second venturi valve **10** can be positioned in the exhaust duct **904** along with a second filter **912**. The ICU suite **900** can be equipped with a room monitor **916**, which can be in communication with a room management display **918** or a multi-room monitor **920**, for example located at a nurses' station **922**.

FIG. **14** is a schematic illustration of the venturi valve of FIG. **1** for use in a biosafety level laboratory (BSL) or containment suite with rooms **1000**, **1040**, **1080**. The BSL rooms **1000**, **1040**, **1080** include supply ducts **1002** and exhaust ducts **1004**. First venturi valves **10** can be positioned in the supply ducts **1002** along with reheat valves **1006**. Second venturi valves **10** can be positioned in the exhaust ducts **1004**. The BSL rooms **1000**, **1040**, **1080** can be equipped with room monitors **1016**, which can be in communication with a room management display **1018** or multi-room monitors **1020**, for example located at a monitoring station **1022**.

FIG. **15** is a schematic illustration of the venturi valve of FIG. **1** for use in a chemistry and wet laboratory **1100**. The laboratory **1100** includes a supply duct **1102** and an exhaust duct **1104**. A first venturi valve **10** can be positioned in the supply duct **1102** along with a reheat valve **1006**, a humidity sensor **1108**, and a first filter **1110**. A second venturi valve **10** can be positioned in the exhaust duct **1104** along with a second filter **1112**. The laboratory **1100** can be equipped with room condition displays **1114**, a multi-point monitor **1115**, and room monitors **1116**, which can be in communication with a room management display **1118** or a multi-room monitor **1120**, for example located at a monitoring station **1122**. The laboratory **1100** also includes a laboratory fume hood **1130**, which is in communication with a third venturi valve **10** and a second exhaust duct **1104**.

The laboratory fume hood **1130** is a ventilated enclosure where harmful materials can be handled safely. Access to the interior of the hood **1130** is through an opening, which is closed with a sash that typically slides up and down to vary the opening into the hood **1130**. The velocity of the air flow through the hood opening is called the face velocity. The more hazardous the material being handled, the higher the recommended face velocity, and guidelines have been established relating face velocity to toxicity. Typical face velocities for laboratory fume hoods are 60 to 150 feet per minute (fpm), depending upon the application. When an operator is working in the hood **1130**, the sash is opened to allow free access to the materials inside. The sash may be opened partially or fully, depending on the operations to be performed in the hood **1130**. While fume hood and sash sizes vary, the opening provided by a fully opened sash is on the order of ten square feet. Thus, the maximum air flow which the blower must provide is typically on the order of 600 to 1500 cubic feet per minute (CFM). The sash is closed when the hood **1130** is not being used by an operator. It is common to store hazardous materials inside the hood **1130** when the hood **1130** is not in use, and a positive air flow must therefore be maintained to exhaust contaminants from such materials even when the hood is not in use and the sash is closed.

The hood **1130** is connected to a fume hood controller **1132**, according to some embodiments of the invention and as shown in FIG. **16**, which can accurately monitor and/or control the ventilation of the fume where proper face velocity or air volume is necessary. The fume hood controller **1132** can be used to modulate the exhaust volume of the venturi valve **10** to maintain a constant face velocity (e.g., 500 CFM). The fume hood controller **1132** can be capable of standalone operation and both visual and audible alarms. The fume hood controller **1132** can be used in the following critical environments: wet chemistry, open bench, bio-containment laboratories, pharmacies, clean rooms, and animal research facilities. The fume hood controller **1132** provides several configurations, including variable volume, constant volume, and low volume. The fume hood controller **1132** can be configured for direct velocity control, vertical sash sensing, horizontal sash sensing, a combination of vertical and horizontal sash sensing, and constant volume sensing. The fume hood controller **1132** can support the venturi valve **10**, exhaust air terminals, mechanical linear plunger valves, and variable frequency drives. The fume hood controller **1132** can incorporate a microprocessor-based controller with a full color touch screen interface and can be used as a monitor only or as a complete system controller. The fume hood controller **1132** includes analog inputs/outputs and communications in order to integrate with the venturi valve **10**, along with the various controllers and monitors described herein, in addition to existing building automation systems.

The fume hood controller **1132** can allow the user to locally select from "IN USE" and "STANDBY" modes, and can include various energy saving features, such as night set back, occupancy set back, and sash user notification.

The fume hood controller **1132** can be capable of several different feedback configurations, including closed-loop volumetric constant face velocity control. The fume hood controller **1132** can measure the area of the fume hood opening (vertical sash, horizontal sash, or combination sash), including any fixed area with a bypass to determine total sash opening. The measured sash area can be used to proportionally control the hood's exhaust venturi valve **10** to maintain a constant average face velocity.

The fume hood controller **1132** control strategy can be a closed loop system that utilizes feedback to measure the actual system operating flow parameter. The feedback signal can be sent back to the controller where it is compared to the desired system set point. The fume hood controller **1132** can be capable of multiple set points including at least "IN USE", "STANDBY", "NIGHT", "UNOCCCUPIED", and "SHUT DOWN" modes. The fume hood controller **1132** can display the actual face velocity, time in current mode, sash open area, and CFM.

The fume hood controller **1132** can also operate according to open-loop with verification feedback for volumetric constant face velocity control. The fume hood controller **1132** can utilize linear valve position and control the position of the damper panel **36** of the venturi valve **10** to control flow.

In addition, the fume hood controller **1132** can operate according to direct velocity control. The fume hood controller **1132** can substantially continually measure the bi directional flow between the interior of the hood **1130** and the reference space. The fume hood controller **1132** can be capable of measuring a face velocity of 0-200 FPM (0-61 m/s). The fume hood controller **1132** can be capable of monitoring actual hood exhaust flow independent from control. The fume hood controller **1132** can measure flow from the closed loop exhaust valve or an air flow station.

Also, the fume hood controller **1132** can operate according to closed-loop constant flow and variable constant flow. The fume hood controller **1132** can maintain a constant or variable constant exhaust flow. The fume hood controller **1132** control strategy can be a closed loop system that utilizes feedback to measure the actual system operating flow parameter. The feedback signal can be sent back to the controller where it is compared to the desired system set point.

In addition, the fume hood controller **1132** can operate according to open-loop with verification constant flow and variable constant flow. The fume hood controller **1132** can maintain a constant or variable constant exhaust flow. The fume hood controller **1132** can utilize linear valve position and control the position of the damper panel **36** of the venturi valve **10** to control air flow. The valve **10** can include an integral air flow station for actual flow measurement feedback.

The fume hood controller **1132** can maintain the face velocity-volume set point to ensure fume hood containment. The actual velocity can be within ±10% of the set point within one second. The system can be capable of at least a 5:1 turndown. The fume hood controller **1132** can achieve 90% of volume within one second of the sash reaching 90% of its final position.

The fume hood controller **1132** can have multiple modes with each mode being capable of local configuration via touch screen or remote configuration via a network connection. The fume hood controller **1132** can include automated sequences and timing features for energy savings. The mode and condition of the space can be chosen with a single user change and not require the user to make changes to multiple parameters. The fume hood controller **1132** can display the time the hood **1130** is in each mode, including normal or alarm conditions.

For each of the feedback configurations described above, the fume hood controller **1132** can display the hood status/condition in a number of different manners. One hood status is "In Use (No Alarm)" in which the fume hood controller **1132** can display a green screen with hood air flow graphic and no audible alarm. The fume hood controller **1132** can display current FPM or m/s. Another hood status is "In Use (Loss of face velocity inside alarm delay)" in which the fume hood controller **1132** can display a green screen with a caution graphic and can flash an additional message indicating the hood **1132** is not maintaining air flow and prompt the user to close the sash. Another hood status is "In Use (Loss of face velocity Alarm)" in which the fume hood controller **1132** can display a red screen with an alarm graphic and flash an additional message indicating the hood **1130** is not maintaining air flow and prompt the user to close the sash. Yet another hood status is "Standby/Night Alert/Occupancy Alert" in which the fume hood controller **1132** can display a blue screen with a standby graphic. In all modes, when the fume hood controller **1132** screen is touched, it can display the following information: time hood has been in current mode, sash open area, and CFM/l/s.

For each of the feedback configurations described above, the fume hood controller **1132** can be capable of supporting multiple hood control strategies and associated set points. The fume hood controller **1132** can have several constant face velocity set points, for example, including the following: "In Use (normal operation)"; "Standby (unoccupied and night set back)"; "Emergency Override (maximum flow)"; "In Use set point XXX FPM (m/s)"; and "Standby/Night/Unoccupied set point XXX FPM (m/s)".

The fume hood controller **1132** can include an emergency override button clearly indicated on the touch screen interface. The emergency override can have a dedicated audible and graphic alarm when activated. The emergency override can drive the exhaust to maximum flow. The emergency override can be initiated from the fume hood controller **1132** or remotely from a contact or network. A user can locally mute the emergency override of the fume hood controller **1132** from the touch screen. The audible alarms can be silenced via a network.

The fume hood controller **1132** can also provide safe energy sash alerts for hoods with sash sensors. In some embodiments, the fume hood controller **1132** can be capable of activating an alarm based on a light level sensor and a hood open sash area. In other embodiments, the fume hood controller **1132** can be capable of activating an alarm based on occupancy and hood open sash area. The FHC shall clearly display the sash alarm status on the touch screen. The fume hood controller **1132** can substantially continually monitor the sash open area. The fume hood controller **1132** can alarm if the hood face opening is greater than a particular square footage. The alarm can have a configurable time delay and can be reset when the hood open area is lowered below opening threshold.

The fume hood controller **1132** can have an RS-485 serial network interface that supports native BACnet MS/TP. The fume hood controller **1132** can also support Modbus, N2 and Lon with optional card.

It will be appreciated by those skilled in the art that while the invention has been described above in connection with particular embodiments and examples, the invention is not necessarily so limited, and that numerous other embodiments, examples, uses, modifications and departures from the embodiments, examples and uses are intended to be encompassed by the claims attached hereto. The entire disclosure of each patent and publication cited herein is incorporated by reference, as if each such patent or publication were individually incorporated by reference herein. Various features and advantages of the invention are set forth in the following claims.

The invention claimed is:

1. A venturi valve for use in an indoor critical environment to regulate [air] *fluid* flow, the venturi valve positioned in an exhaust a duct, the venturi valve comprising:

a [substantially cylindrical pipe] *tube* including at least a first section having a first [diameter] *perimeter* and a second section having a second [diameter] *perimeter*, the first [diameter] *perimeter* being larger than the second [diameter] *perimeter*, wherein the first section is coupled to the second section by a third section that is defined by a reducing [diameter] *perimeter*;

a high pressure sensing assembly including a first pneumatic tube positioned around the first [diameter] *perimeter*, the first pneumatic tube coupled to [a] *at least two* first [plurality of air] *fluid* inlet ports, the *at least two* first [plurality of air] *fluid* inlet ports [spaced around] *located in* the first [diameter] *perimeter* to sense a first average static pressure at the first [diameter] *perimeter*;

a low pressure sensing assembly including [a second pneumatic tube positioned around the second diameter, the second pneumatic tube coupled to a] *at least two* second [plurality of air] *fluid* inlet ports, the *at least two* second [plurality of air] *fluid* inlet ports [spaced around] *located in* the second [diameter] *perimeter* to sense a second average static pressure at the second [diameter] *perimeter*;

a differential pressure transducer coupled to the high pressure sensing assembly and the low pressure sensing assembly, the differential pressure transducer generating a differential pressure signal based on the first average static pressure and the second average static pressure;

a damper assembly coupled to the [substantially cylindrical pipe] *tube*, the damper assembly including a damper and a damper actuator *device*; and

a controller connected to the differential pressure transducer and the damper actuator *device*, *wherein* the controller determining a current flow rate of [air] *fluid* into the indoor critical environment based on the differential pressure signal, the controller operating the damper actuator *device* based on the current flow rate in order to provide a desired flow rate of [air] *fluid* out of the indoor critical environment until the indoor critical environment is cleared through the exhaust duct and a pressure of the indoor critical environment *is one of negative*, neutral *and positive* relative to adjacent spaces.

[**2**. The valve of claim **1** wherein at least one of the first plurality of air inlet ports and the second plurality of air inlet ports each include at least six equally spaced inlet ports.]

3. The valve of claim **1** wherein at least one of the *at least two* first [plurality of air] *fluid* inlet ports and the *at least two* second [plurality of air] *fluid* inlet ports are coupled to an internal surface of the [substantially cylindrical pipe] *tube* in order to be surface flush.

4. The valve of claim **1** wherein at least one of the *at least two* first [plurality of air] *fluid* inlet ports and the *at least two* second [plurality of air] fluid inlet ports minimally extend into an internal portion of the [substantially cylindrical pipe] *duct*.

5. The valve of claim **1** wherein at least one of the *at least two* first [plurality of air] *fluid* inlet ports and the *at least two* second [plurality of air] *fluid* inlet ports do not bisect the [substantially cylindrical pipe] *tube*.

6. The valve of claim **1** wherein at least one of the *at least two* first [plurality of air] *fluid* inlet ports and the *at least two* second [plurality of air] *fluid* inlet ports do not substantially impede air flow through the [substantially cylindrical pipe] *tube*.

7. The valve of claim **1** wherein at least one of the *at least two* first [plurality of air] *fluid* inlet ports and the *at least two* second [plurality of air] *fluid* inlet ports extend up to about two inches into an internal portion of the [substantially cylindrical pipe] *tube*.

8. The valve of claim **1** wherein the indoor environment includes at least one of a health care facility, a patient room, an isolation room, a procedure room, a pharmacy, an oncology room, a laboratory, an operating room, a research facility, a wet chemistry laboratory, a bio-containment room, a clean room, a life science facility, a vivarium, and an open bench laboratory.

[**9**. The valve of claim **1** wherein the venturi valve is used for one of supply air flow, exhaust air flow, hood air flow, return air flow, and bypass air flow.]

10. The valve of claim **1** and further comprising a cover surrounding the differential pressure transducer, the high pressure sensing assembly, and the low pressure sensing assembly.

11. The valve of claim **1** and further comprising an actuator mounting bracket coupled to the [substantially cylindrical pipe] *tube*, the damper, and the damper actuator *device*.

12. The valve of claim **1**, wherein the first section and the second section each have substantially constant [diameters] *perimeters* along a length thereof.

13. The valve of claim **12**, wherein the [substantially cylindrical pipe] *tube* further includes a fourth section having an increasing *diameter perimeter*, and a fifth section having a [diameter] *perimeter* substantially equal to the first section, and wherein the fourth section is disposed between the second section and the fifth section.

14. A venturi valve for use in an indoor critical environment to regulate fluid flow, the venturi valve positioned in an exhaust a duct, the venturi valve comprising:

a tube including at least a first section having a first perimeter and a second section having a second perimeter, the first perimeter being larger than the second perimeter, wherein the first section is coupled to the second section by a third section that is defined by a reducing perimeter;

a high pressure sensing assembly including at least two first fluid inlet ports, the at least two first fluid inlet ports located in the first perimeter to sense a first average static pressure at the first perimeter, said first perimeter having a first constant perimeter portion along a longitudinal axis of said venture valve, said high pressure sensing assembly being located in said first constant perimeter portion;

a low pressure sensing assembly including at least two second fluid inlet ports, the at least two second fluid inlet ports located in the second perimeter to sense a second average static pressure at the second perimeter, said second perimeter having a second constant perimeter portion along a longitudinal axis of said venture valve, said low pressure sensing assembly being located in said second constant perimeter portion;

a differential pressure transducer coupled to the high pressure sensing assembly and the low pressure sensing assembly, the differential pressure transducer generating a differential pressure signal based on the first average static pressure and the second average static pressure;

a damper assembly coupled to the tube, the damper assembly including a damper and a damper actuator device; and

a controller connected to the differential pressure transducer and the damper actuator device, wherein the controller determining a current flow rate of fluid into the indoor critical environment based on the differential pressure signal, the controller operating the damper actuator device based on the current flow rate in order to provide a desired flow rate of fluid out of the indoor critical environment until the indoor critical environment is cleared through the exhaust duct and a pressure of the indoor critical environment is one of negative, neutral and positive relative to adjacent spaces.

15. The valve of claim 14 wherein at least one of the at least two first fluid inlet ports and the at least two second fluid inlet ports extend up to about two inches into an internal portion of the tube.

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