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(54) HEATED REPLACEMENT AIR SYSTEM FOR COMMERCIAL APPLICATIONS

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(60) Provisional application No. 60/556,097, filed on Mar. 25, 2004.

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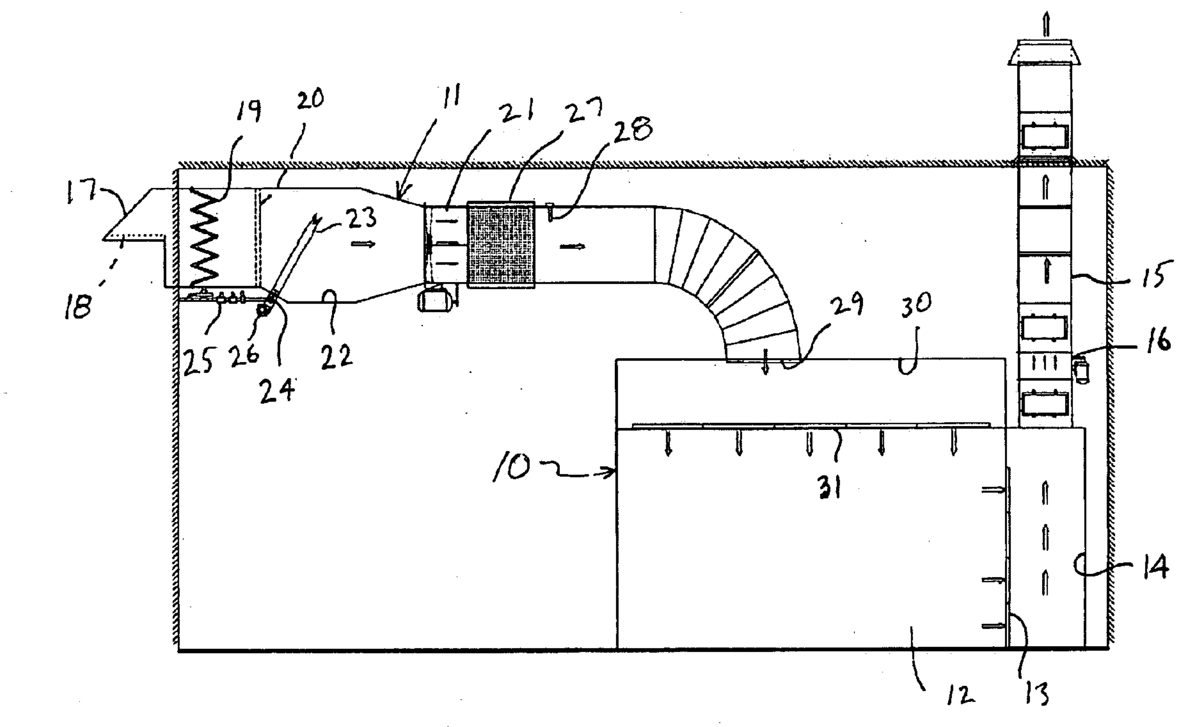
(57) ABSTRACT

Apparatus and a method for providing heated replacement air to a paint spray booth or other commercial process which requires heated make-up air to replace exhausted air. A blower draws outside air through a filter and an injection chamber prior to delivering the air to the process. Hot gases from a burner are injected into the injection chamber and mixed with the replacement air to adjust the temperature of the replacement air. The burner uses combustion air which is separate from the replacement air. The flow rate of the exhaust air and the replacement air can be adjusted to meet changing needs of the process. The BTU output from the burner is adjusted to maintain a desired replacement air temperature.



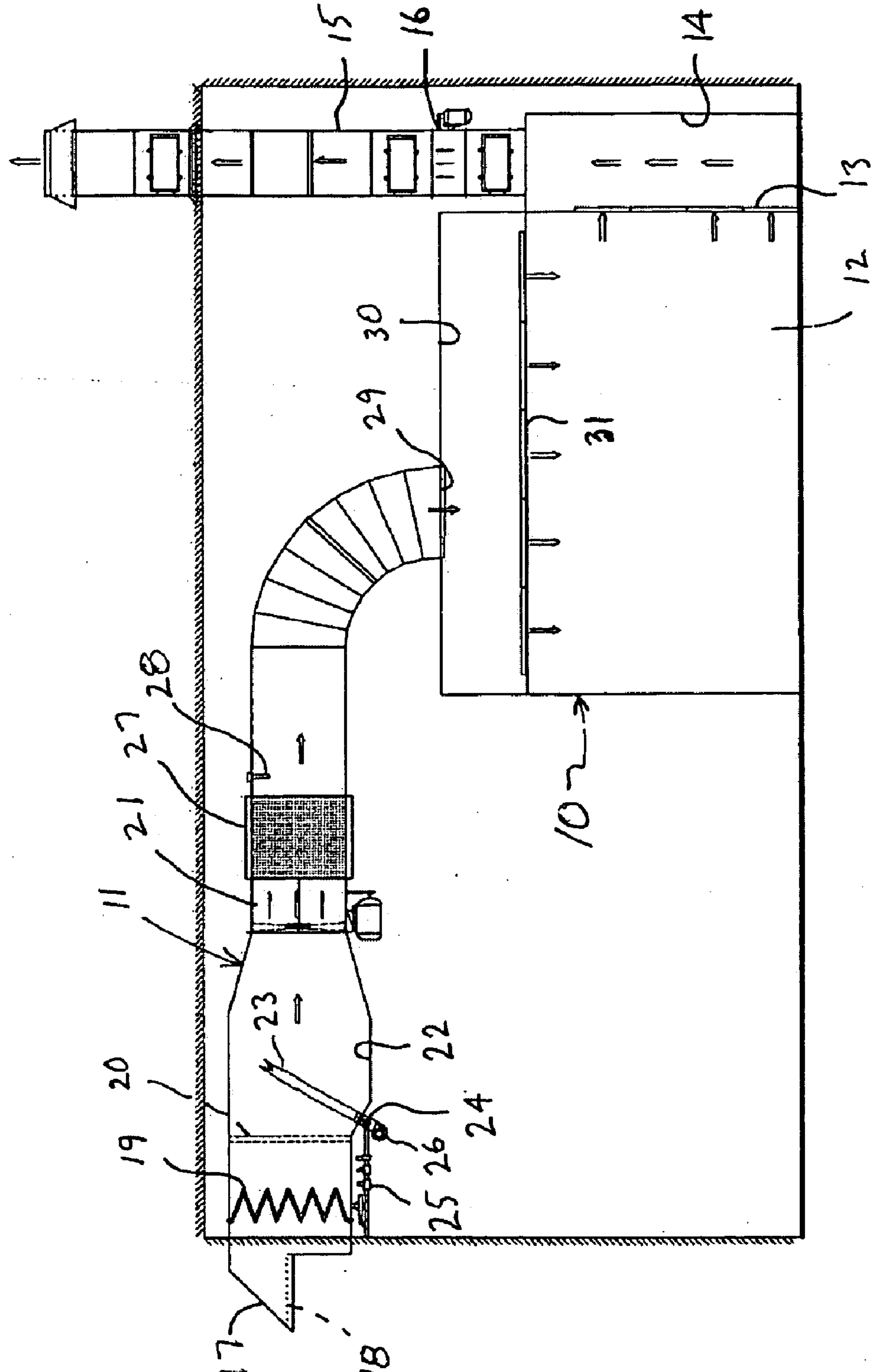


Fig. 1

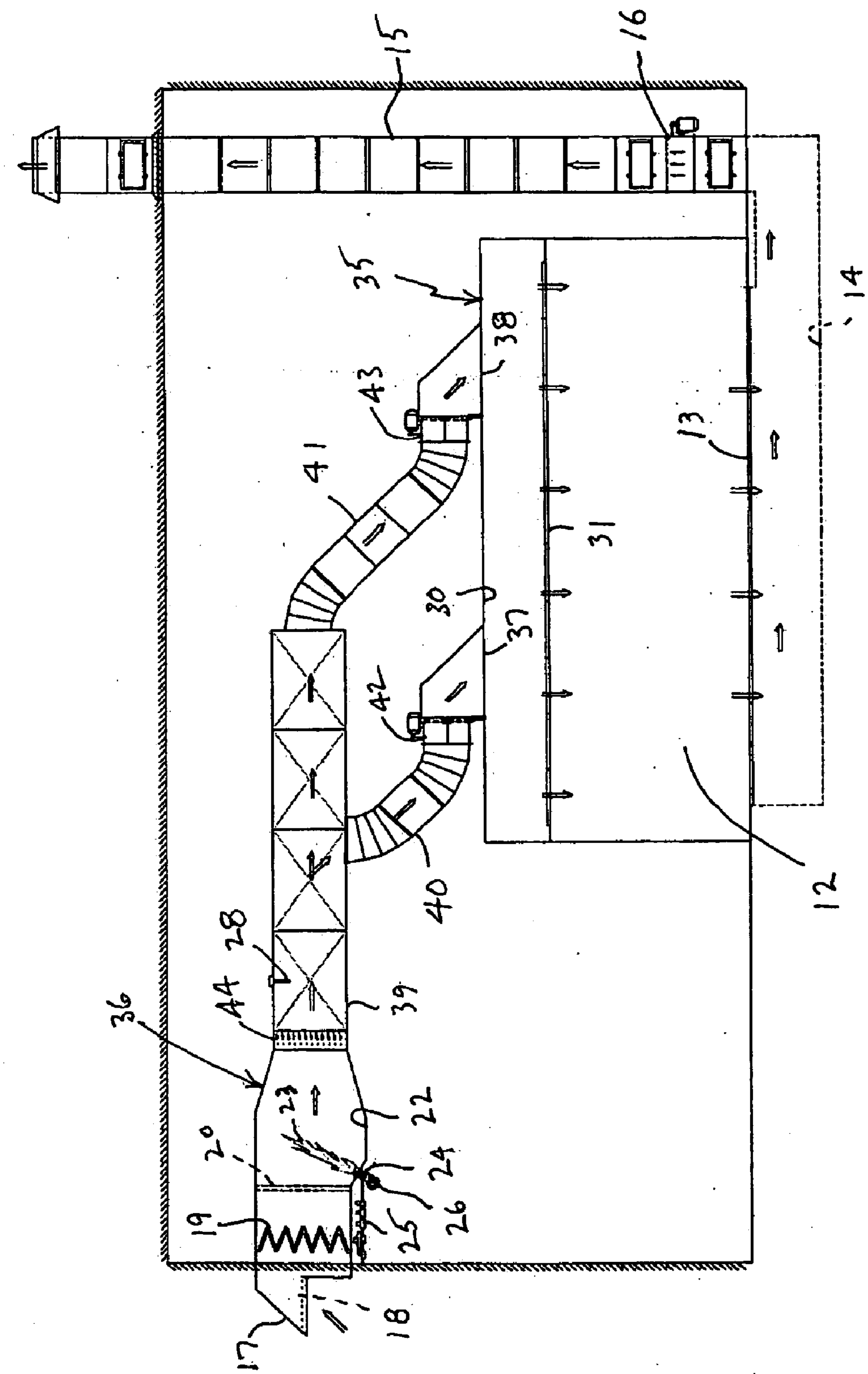


Fig. 2

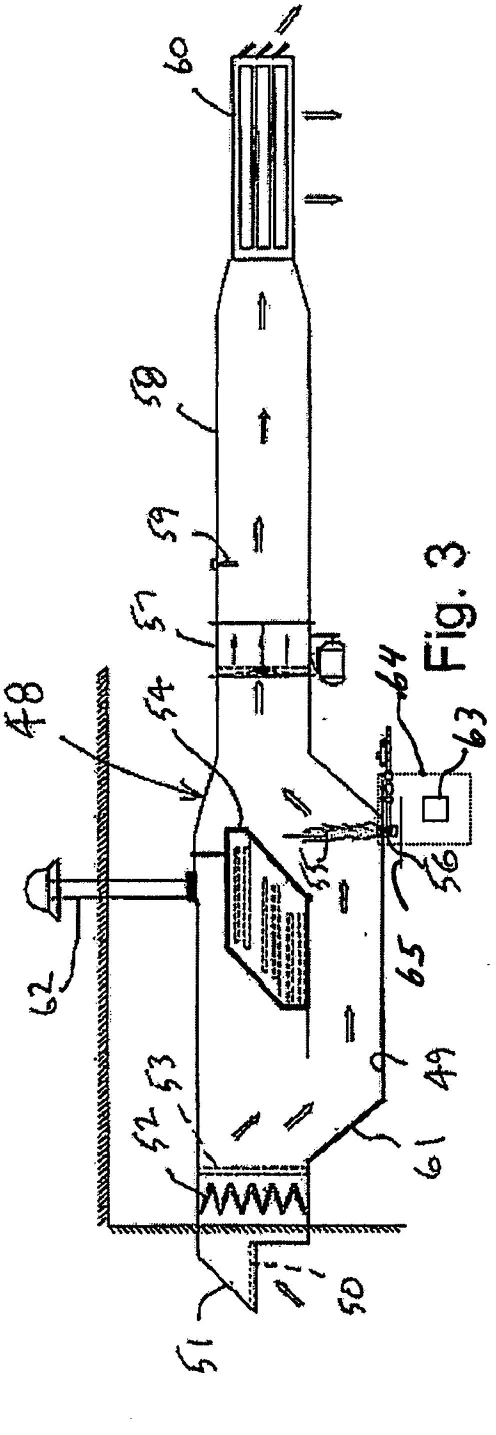

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Fig. 3

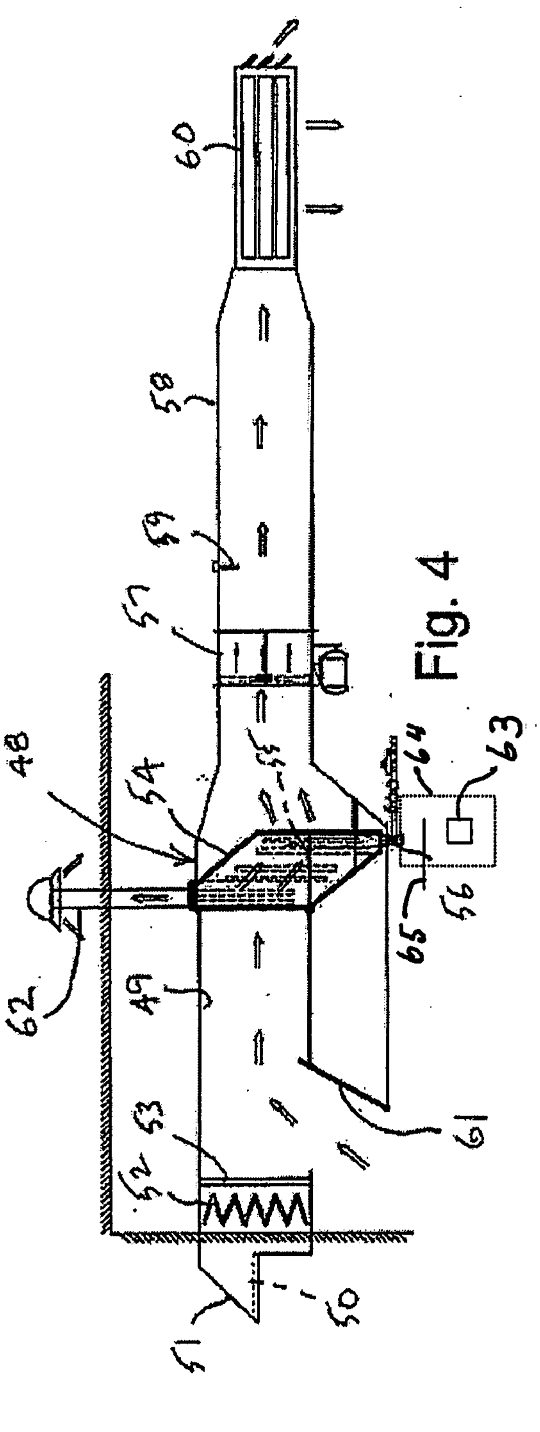
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Fig. 4

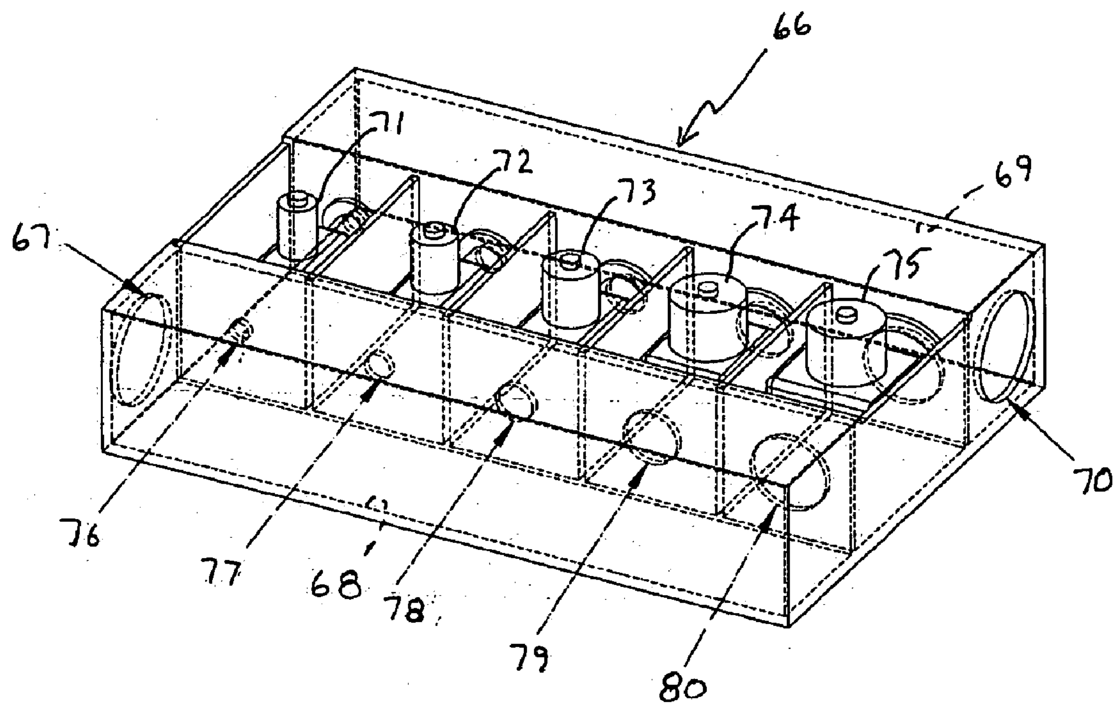

Fig. 5

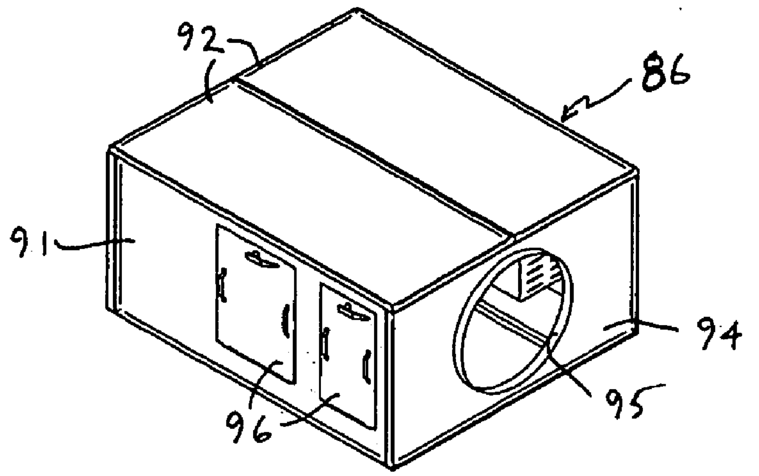
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Fig. 6

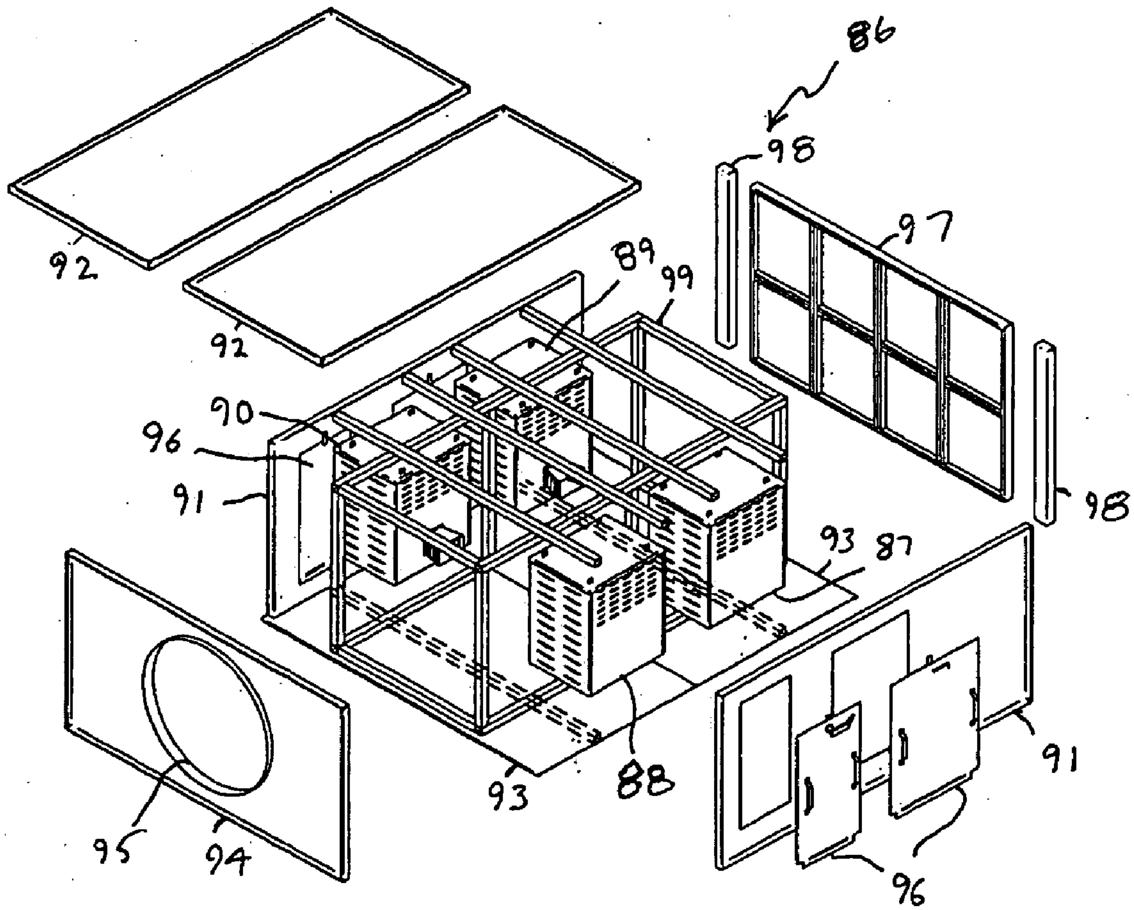
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Fig. 7

HEATED REPLACEMENT AIR SYSTEM FOR COMMERCIAL APPLICATIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Applicants claim priority to U.S. Provisional Patent Application Ser. No. 60/556,097 filed Mar. 25, 2004. This application is a continuation of Ser. No. 11/088,664 filed Mar. 24, 2005, which is expressly incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable.

TECHNICAL FIELD

[0003] The invention relates to a system for providing heated replacement air to a commercial or industrial process, such as to a paint spray booth.

BACKGROUND OF THE INVENTION

[0004] The process of applying atomized liquid coatings and adhesives generates potentially dangerous gaseous and particulate by-products that are controlled or managed by confining them in an enclosure known as a spray booth and conveying them away from the process by entraining them in a moving air stream. This exhaust air stream typically passes through one or more stages of filtration to remove the particulates before the gaseous or vaporous by-products are exhausted into the atmosphere. The volume of the exhaust air stream varies according to the size of the spray booth and may range, for example, from 3,000 cubic feet per minute (CFM) to more than 50,000 CFM. This equates to 30 to 150 lineal feet per minute within the spray booth in the direction of air flow. Provision may be made to replace the exhausted air volume.

[0005] Since most coating processes are vulnerable to quality rejects caused by dirt or other foreign airborne objects, prudent finishing process operators equip their facilities with air make-up unit. Air make-up units have a three fold function. First, they supply the process with the required replacement air. Second, they filter the replacement air. Third, they heat or condition it. An air make-up unit may be directly coupled to the spray booth or it may dump replacement air to the area surrounding the booth. Air make-up units are designed to include a heat source with sufficient thermal capacity to warm the volume of replacement air to the desired temperature on the anticipated coldest day. Typically, a fan or blower in the air make-up unit pushes or pulls the entire replacement air stream through a complex assembly that includes filters, dampers, and a heat source which is usually a gas burner.

[0006] Historically, environmental and worker health and safety regulations have empirically established minimum air velocities for spray booths. The overwhelming majority of installed spray booths are equipped with fixed speed exhaust fans or blowers. While exhaust air velocities change as the particulate filtration system loads, the pressure drop increase across the filtration system is usually limited to 0.5 inches of water column and produces a corresponding reduction in exhaust air volume in the range of 20%. Since the spray booth exhaust air volume is essentially fixed in any given installation, the volume of air the associated air make-up unit is required to provide also is fixed. Hence, the air make-up unit like the spray booth is usually equipped with a fixed speed fan or blower. In addition, the gas burner's operating efficiency is dependent on maintaining a predetermined air velocity through the burner mechanism. This precludes making significant changes to a given air make-up unit delivered air volume without mechanically reconfiguring the unit.

[0007] The attempts of placing a premix burner in the air stream in the early days of air replacement technology were short lived because the panel fans that were used were loud and could not handle the static loads of the supply plenum filters. Once the capability of the blower with the ability to handle additional static was introduced the most effective method for air replacement was established as the paradigm. Direct fired inline burners with associated profile plates that adjust the airflow across the burner proved to be the most efficient technology. These profile plates were first considered as fixed, as was the airflow through the unit. With changes in technology these profile plates have now become adjustable and the range of acceptable airflow across the burner has been increased.

[0008] In a traditional air make-up unit system, all of the replacement air is drawn across the burner assembly and any change in the delivered air volume will change the burner's air supply. This causes it to operate under less than optimum conditions. For this reason, traditional air make-up units are designed with fixed speed fans. Any reductions in delivered air volume are usually accomplished by partially closing a damper on the output of the air makeup unit (AMU) to reduce the output volume or changing the speed of the blower with a variable frequency drive (VFD). A VFD adjusts the rotational speed of the fan motor to keep the ventilation system balanced. The cost to apply a VFD to control the motor for the unit with an in-line burner is significant because a larger motor size is needed for a system with an in-line burner due to the higher static load.

[0009] In an enclosed booth system, the air make-up unit discharges directly into the process within the booth. Based upon the assumption the air make-up unit operates at a fixed speed, the exhaust fan speed is varied as required to keep the booth balanced. Prior to the advent of electronic VFD units, a damper was placed in the exhaust stack. This damper added an adjustable static load to the fan. The damper was reduced as the overspray arresting filters loaded to maintain a constant air velocity through the booth. The range of actual air velocity changes under this or other schemes is limited.

[0010] Unfortunately, the resulting somewhat arbitrarily established, fixed volume air flow found in a typical spray booth system is not the optimum environment for efficiently applying a consistent high quality finish. Significant process economies, as well as improvements in the quality of the applied finish, can be achieved by reducing the air velocity in any given spray booth. A few astute finishing process owners have "tuned" their finishing process by adjusting the exhaust air volume of individual spray booths and making corresponding adjustments in the volume of replacement air delivered by the associated air make-up unit as well as the necessary mechanical changes to the air make-up units configuration. However, no one has designed an air make-up unit/spray booth system that can be mass produced, yet economically facilitate the tuning of individual installations to the precise needs of their respective finishing processes while simultaneously maintaining optimum air make-up unit operation.

[0011] In prior art spray booths, replacement air flow is either on or off because the effort required to vary its volume was complex and time consuming. The burner required a fixed combustion air velocity to achieve the necessary clean burn characteristics and therefore the overall replacement air volume couldn't be changed.

BRIEF SUMMARY OF THE INVENTION

[0012] The invention is directed to a direct gas fired heat source arrangement for air replacement or make-up units used in conjunction with spray booths and other industrial and commercial processes. The invention permits the replacement air volume to be varied over a wide range without compromising the integrity of the burner's combustion process and without requiring the expensive and somewhat tedious mechanical reconfiguration of the burner assembly. The invention utilizes a plurality of smaller burners positioned outside of the primary replacement air passage. The burners are operated to inject a controlled amount of heat into the primary replacement air passage to control the temperature of replacement air flowing through the passage. Each burner is individually configured in such a manner that it is always supplied with the necessary volume of air to insure complete combustion. When coupled with a modified spray booth and the appropriate controls, this invention allows the exhaust air flow rate and total volume to be optimized for the finishing process it protects, thereby increasing the process' coating application transfer efficiency, decreasing the emission of volatile organic compounds (VOC's) and particulates, increasing the quality of the applied finish, and significantly reducing the process operating cost. The invention provides the production economics associated with the manufacture of standard equipment packages while simultaneously enabling individual finishers to customize their air make-up unit—spray booth systems to the processes ventilation requirements solely by programming system controls.

[0013] Similar air handling systems are used to replace the significant quantities of process air exhausted to control the potentially hazardous build-up of gaseous and/or particulate emissions generated by other mid-sized and large commercial and industrial processes including, but not limited to wood working dust collection, welding fume collection, fiberglass reinforced plastic lay-up, sandblasting, commercial/industrial dry cleaning and cooking. The invention offers substantial process and economic benefits in these applications.

[0014] The invention allows the replacement air units to be thought of as modular components, not part of a unit that is shipped to the jobsite on a flatbed truck. Processes that require very clean air now have the ability to have the filtration system designed specific to the application and not to be always contained within the confines of the AMU. The balance problem that existed when a single blower had to push air down different interconnecting duct work sections can now be better controlled by decentralized distribution fans that can have their speeds adjusted via the drive pulleys at start-up. This can achieve the desired balance, or the motors can be operated with variable speed drives (VFD's) which would better address the changes in static loads caused by filter loading.

[0015] The air replacement system of the invention can produce significant energy savings that are not possible with current systems. Although the cost of the self contained burner is greater than the simple in-line burner, the ability to let the process have less restrictive limits with regard to the volume of air required and to allow the process to demand only the volume that is required is a feature of the invention. Efficiencies that can now be gained by altering the air volume will produce significant savings in energy costs.

[0016] The replacement air system of the invention improves the overall efficiency and effectiveness of a process which consumes high levels of fossil fuels to reduce the energy cost for those who use the system. It also reduces emissions from burning excessive amounts of fossil fuels. The system is unique because it allows optimization of air being consumed by the spray booth or other process that contaminates the air, thereby opening a new concept to improve efficiency. It has been thought that no improvement could be made to the direct fired burner since all the heat goes into the air. However, with the invention the volume of air being consumed can be adjusted, which has a direct relationship to the overall fuel consumption.

[0017] Various objects and advantages of the invention will become apparent from the following detailed description of the invention and the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. **1** is a diagrammatic view of a paint spray booth with a heated replacement air system according to one embodiment of the invention;

[0019] FIG. **2** is a diagrammatic view of a paint spray booth with a heated replacement air system according to a second embodiment of the invention;

[0020] FIG. **3** is a diagrammatic view of a dual mode heated replacement air system according to a further embodiment of the invention, showing the system operating in a direct fire operation;

[0021] FIG. **4** is a diagrammatic view of the dual mode heated replacement air system of FIG. **3**, showing the system operating in an indirect heat operation;

[0022] FIG. **5** is a perspective view of a multi-port digital gas flow control valve;

[0023] FIG. **6** is a perspective view of a multi-burner apparatus for injecting heat into a flow of replacement air for an industrial or commercial process such as a paint spray booth; and

[0024] FIG. **7** is an exploded perspective view of the apparatus of FIG. **6**.

DETAILED DESCRIPTION OF THE INVENTION

[0025] The invention is directed to a heated replacement air system for an industrial or commercial process, and to apparatus which allows for the independent adjustability of the replacement air volume flow and the BTU energy applied to that air volume flow. The system is described herein specifically for use with industrial and commercial spray paint booths. However, the system also can be used with similar processes where varying the air volume being moved through the system and the temperature of the air during some periods of the process might allow the process to still function well within all process and safety requirements.

[0026] Turning to FIG. **1** of the drawings, an industrial paint spray booth **10** is shown incorporating a heated replacement air system **11** according to one embodiment of the invention. The spray booth **10** includes a work chamber **12** where objects are painted. The size of the chamber **12** will depend on the size of the objects which are painted. During painting, air and any entrained overspray particles and solvent fumes are exhausted through a filter **13** into a plenum **14**. Exhaust air is withdrawn from the plenum **14** through an exhaust stack **15** by a motor driven exhaust fan **16**. The apparatus for filtering and exhausting air from the spray booth **12** may be of any conventional type. For example, the filter **13** may be as simple as a replaceable glass fiber filter, or may be a water system which washes the exhaust air, or may include an advanced system for removing VOC's from the exhaust air.

[0027] Normally, the exhaust air is vented to the atmosphere outside of a building housing the spray booth **10**. As air is exhausted from the building housing the spray booth **10**, it is necessary to provide an equal amount of replacement air. If the ambient temperature is sufficiently high, the replacement air may be filtered ambient air drawn from outside of the building. However, on cooler days and especially in northern climates, it is necessary to heat the replacement air to the temperature required by the painting process.

[0028] The system **11** draws replacement air for the finishing process from the area surrounding the perimeter of the facility where the spray painting booth **10** or process contaminating the air is housed. Replacement air is drawn in through an air intake hood **17** or louvers which rejects rain. A screen **18** prevents birds and animals from entering the air intake hood. The replacement air is drawn through inlet filters **19** to remove airborne particulates that can cause defects in the uncured paint film should they be deposited thereon.

[0029] The outside air is separated from the process during times of non-operation by a motorized damper or shutter **20**. The location of the damper or shutter **20** will be a function of where the building boundary is located with the desire to prevent outside air from entering the building perimeter when replacement air is not required. The controls for the replacement air system **11** will ensure the damper or shutter **20** is full open prior to the need for replacement air. Preferably, the damper or shutter **20** is of a type which keeps the static load on the system to a minimum during operation of the system **11**.

[0030] A variable speed fan **21**, preferably a tube axial distribution fan, draws normally cool to cold ambient air through the hood **17**, the filter **19** and the damper or shutter **20** into a connecting injection chamber **22**. In the chamber **22**, the replacement air is blended with a stream of high temperature gas **23** which is injected into the replacement air flowing through the chamber **22** by a nozzle mix gas burner **24**. Although only one burner **24** is illustrated, it will be appreciated that a number of burners may be provided to inject high temperature gas into the chamber **22** to provide the required BTU's. The BTU energy in the high temperature gas **23** is controlled by a modulating gas valve **25**. Combustion takes place in the gas burner **24**. The gas burner **24** includes a blower **26** which supplies the combustion air and also produces sufficient pressure to inject the high temperature gas stream **23** into the chamber **22**.

[0031] The variable speed distribution fan **21** pulls the replacement air through the injection chamber **22** to meet the air volume requirement of the spray booth **10**. The distribution fan **21** also thoroughly mixes and blends the high temperature air **23** from the system burner(s) **24** before being discharged into the spray booth **10**. A tube axial distribution-fan **21** can be used with this invention because the static load placed on the system is within the operation parameters for a tube axial fan. However, the invention is not limited to its use and would function well with other forms of air moving devices.

[0032] An optional muffler **27** can be mounted after the distribution fan **21** to reduce the noise level. If the injection chamber **22** and the distribution fan **21** were to be located outside the building, the muffler would also add to the insulation factor of the interconnecting duct work. Due to the higher frequency noise generated by a tube axial fan, the noise from a tube axial fan is easier to attenuate than the noise generated from a blower.

[0033] If only one distribution fan **21** is used in the system **11**, a temperature sensor **28** used for temperature control is located after the distribution fan. If desired, the distribution fan **21** can be moved to a location significantly remote from the burner **24** to improve the overall effectiveness of the air replacement system. This invention allows the distribution fan(s) **21** to be placed at or near one or more supply points **29** to a spray booth supply plenum **30** to better control the distribution of the air. The spray booth supply plenum **30** is connected through filters **31** to deliver clean, heated replacement air to the work area **12**. The prior art technology forces a single blower to be located close to the burner because the area between the burner and the blower is under significant static load. This restriction forces the air to be pushed down the interconnecting duct work.

[0034] FIG. **2** shows a downdraft paint spray booth **35** incorporating a heated replacement air system **36** according to a modified embodiment of the invention. Components in the spray booth **35** and in the replacement air system **36** which are identical to those in FIG. **1** are labeled with the same reference numbers. The spray booth **35** is quite large, and may be in excess of 40 feet in length. Such a spray booth may be used, for example, for painting an automobile body. Due to the size of the supply plenum **30**, replacement air is delivered through multiple points. Although two supply points **37** and **38** are illustrated, it will be understood that the number of supply points will depend on the spray booth size and air flow requirements.

[0035] When multiple discharge points from the air replacement system are required to service the spray booth replacement air flow requirements, the splitting of the air from a single centralized distribution fan such as the fan **21** in FIG. **1** can present problems. The replacement air system **36** has multiple distribution fans located at or near the discharge points to the supply plenum. The chamber **22** is connected to a duct **39**, which is shown as splitting into two ducts **40** and **41**. A fan **42** is connected between the duct **40** and is shown mounted in the duct **40** near the discharge point **37** and a fan **43** is shown mounted in the duct **41** near the discharge point **38**. When multiple distribution fans **42**, **43** are located remote from the injection chamber **22**, a mixing device **44** must be used to blend the air to provide a uniform temperature to the air flowing to the ducts **40** and **41**. The temperature sensor **28** is mounted downstream of the mixing device **44**. This mixing device **44** may be, for example, an arrangement of mixing fins designed to create turbulence to mix the air without adding significant static load to the system. Alternately, the mixing device **44** may be an additional fan which both blends the air and assists in addressing the static load of the system. While tube axial fans can be used with the system, the invention is not restricted to the use of any type air moving device.

[0036] There are also multiple options to inject heat utilizing this invention. There are different types of burners that can be applied to this concept. The embodiment of this invention includes the injection of BTU energy in the form of high temperature air from sources where the efficiency of the BTU injection will not be affected by the air volume through the injection chamber. The air for the self contained burner is a small percentage of the total volume of air. At designed maximum air volumes the burner for the typical system will inject less than 5% of the air volume. This air will be pulled from the area around the nozzle mix burner **24** by a self contained blower **26** that puts the optimum amount of air through the burner to achieve an efficient combustion.

[0037] The burners used to inject heat for the system also can be used with a heat exchanger to allow the system to be converted to an indirect fired unit to prevent any byproducts of combustion to be passed into the air stream. This allows the system to recirculate air in a facility for comfort heat. The conversion from a direct fired heat mode to an indirect heat mode may be needed when the area being serviced by the system is a multi-purposed area such as a tech center or a demonstration area that needs comfort heat at times and also houses processes that at times require air to be exhausted from the facility. Rather than having multiple heating systems the system can be adapted to perform both heating modes. Due to the efficiency of direct heat and the increased capability for heat rise with a direct fire burner in the system the conversion capability has significant benefits.

[0038] FIGS. **3** and **4** show a dual mode heated replacement air system **48** according to a modified embodiment of the invention. The system **48** is shown operated in a direct fired mode in FIG. **3** and is shown operated in an indirect heat mode in FIG. **4**. The system **48** includes an injection chamber **49** through which replacement air flows. In the direct fire mode shown in FIG. **3**, fresh outside air is drawn through a screen **50** in a hood **51**, through a filter **52** and through an open damper or shutter **53** into the chamber **49**. An indirect heat exchanger **54** is located in a retracted position, allowing the replacement air to flow below the indirect heat exchanger **54** where it is impinged by a hot gaseous jet **55** from a burner **56**. The heated replacement air is then forced by a fan **57** into a duct **58**. The fan **57** mixes or blends the air before it flows past a temperature sensor **59** before it is delivered through a plenum chamber **60** to a spray booth or other process requiring heated replacement air.

[0039] In the indirect heat mode shown in FIG. **4**, the indirect heat exchanger **54** is moved to extend across the chamber **49** and the damper or shutter **53** is closed to prevent outside air from entering the building. A damper **61** is moved to a position which allows ambient air from inside the building to be drawn into the chamber **49**. The fan **57** draws the inside air through the indirect heat exchanger **54** where it is heated, and delivers the heated air to the duct **58**. The hot gaseous jet **55** from the burner **56** is directed into the heat exchanger **54** where it indirectly heats the replacement air flow. The gaseous jet **55** is then exhausted through a vent stack **62** to a location outside of the building. In the indirect heat mode, combustion production products from the burner **56** do not enter the spray booth. It will be appreciated that the indirect heat mode may be operated for heating either interior air or exterior air, depending on the position of the damper **61**.

[0040] If the burner **56** for the system is located outdoors the blower **63** that supplies combustion air to the burner **56** is enclosed to protect it from the elements. The combustion air required for the burners **56** used in the system is filtered separately or the enclosure **64** that houses the blower **63** that forces the heat into the air stream is connected to the air inlet chamber after the filters **65**.

[0041] Preferably, the burner used to inject high temperature air into the replacement air stream is a self contained burner with a separate blower having the capability of manage flame control as part of the self contained system. The preferred burner is a known nozzle-mix burner with a modulating gas valve. These burners are capable of producing as much as 1 million BTU per foot and work well under most conditions.

[0042] The nozzle-mix burner also can be used with a digital gas control valve **66** of the type shown in FIG. **5**. The valve **66** has a gas inlet port **67** which connects to an inlet manifold **68** and a gas outlet manifold **69** which connects to a gas outlet port **70**. The gas control valve **66** has a plurality of individual open/closed solenoid operated gas valves connected between the inlet manifold **68** and the outlet manifold **69**, with five valves **71**-**75** illustrated. A calibrated orifice is positioned in each flow path between the inlet manifold **68** and the outlet manifold **69**. The orifices control the gas flow between the manifolds **68** and **69** for each of the valves **71**-**75**. An orifice **76** is shown for limiting the gas flow when the valve **71** is opened; an orifice **77** is shown for limiting the gas flow when the valve **72** is opened; and an orifice **78** is shown for limiting the gas flow when the valve **73** is opened; an orifice **79** is shown for limiting the gas flow when the valve **74** is opened; and an orifice **80** is shown for limiting the gas flow when the valve **75** is opened.

[0043] The orifices **76**-**80** may be of uniform size. Alternately, the orifices **76**-**80** may be calibrated to provide different gas flow rates to control the burner's BTU output. For example, the orifice **76** may be calibrated to provide a 50,000 BTU burner output, the orifice **77** may be calibrated to provide a 100,000 BTU burner output, the orifice **78** may be calibrated to provide a 200,000 BTU burner output, the orifice **79** may be calibrated to provide a 400,000 BTU burner output, and the orifice **80** may be calibrated to provide an 800,000 BTU burner output. By selectively opening one or more of the valves **71**-**75**, the burner output may be controlled in 50,000 BTU increments to inject between 50,000 BTU's and 1,550,000 BTU's of heat to the replacement air flow. Substitution of the multi-port digital gas control valve **66** in place of the traditional analog gas valve in the gas line supplying the burner allows a single burner to provide quick response to changes in air volume to precisely maintain the set point temperature of replacement air irrespective of the temperature of the air being drawn into the system's inlet.

[0044] The multi-port digital gas control valve **66** enables the system to quickly and independently adjust the temperature during changes in air volume by pulling the system out of a closed-loop control and calculating the amount of gas that is needed to reach the set point temperature based upon the incoming air temperature and volume flow rate. The initial calculated setting may be the starting point for the closed loop system when control is given back to make minor adjustments. The snap action of the multi-port digital gas control valve **66** allows the volume of replacement air to change quickly without the significant hysteresis that is caused by the proportional integral derivative (PID) input device loops of the traditional analog method. The traditional analog method limits the transition speeds that can be used when changing the air volume to prevent out of tolerance temperature swings during times of ramp up and ramp down in air volume.

[0045] FIGS. **6** and **7** show details of an exemplary self contained multi-burner unit **86** for injecting heat into a flow of replacement air to a paint spray booth or other process which requires heated replacement air. The unit **86** is designed as a stand alone unit which can be shipped as a unit separate from a spray booth to an installation site. The unit **86** has four heat injector burner units **87-90** mounted within a housing formed, for example, from sheet metal side panels **91**, top panels **92**, bottom panels **93** and an end panel **94**. The end panel **94** has a replacement air outlet opening **95** which is adapted to be connected to ducts leading to the spray booth (not shown). One or more fans (not shown) for drawing replacement air through the unit **86** is mounted in the spray booth ducts. The side panels **91** are shown as including service doors **96** for providing access to the burner units **87-90**. A replaceable inlet air filter **97** is mounted in channels **98** to cover the end of the unit **86** opposite the outlet opening **95**. The unit **86** also includes a frame structure **99** for supporting the burner units **87-90** and the panels **91-94**.

[0046] The system may have multiple burners of the same size or of different sizes and of different types to inject heat into the replacement air. Self contained premix, nozzle mix and venturi burners along with other known burners that meet the specification of being self contained units also can be used in the system. In actual practice, the number and size of the individual burners depend upon the maximum anticipated heat requirement of the process the system is supporting.

[0047] Multiple nozzle mix burners can be used where a fixed BTU rate is provided when the demand for heat was greatest and the smaller burner is modulated to address fine temperature adjustments. The turn-down ratio for the nozzle mix burner is rated at 40:1 so having multiple units where larger burners are required will allow improved temperature control when low levels of BTU energy are required.

[0048] For example, in very frigid climates that have sub zero daytime temperatures, a typical 33,000 cfm unit will have a 4 million BTU burner to produce a 110° F. heat rise which will bring the −20° F. air up to 90° F. The minimum BTU level that can be supported by the burner is 100,000 BTU (4 million/40). At 33,000 cfm the temperature rise of 2.8° F., but if the air volume is reduce to 25% that heat rise would be 11.2° F. This is most noticeable when the outside temperature is more moderate. With an outside temperature of 67° F., the minimum air temperature supplied to the process with the burner at its lowest setting becomes 78.2° F. (67°+11.2°). The turn down ratio of the in-line direct fired burners is rated at 30:1 so the low level sensitivity is worse.

[0049] If the tolerance on air temperature for the process is tight, the capability of the system to develop finer resolution can be improved by providing multiple nozzle mix burners. By incorporating dual 2 million BTU burners where one with a simple on/off control (the "drone") is engaged at full output once the maximum of the modulated unit has reached its maximum output. Better control may be achieved if the drone burner is slightly smaller than the modulated burner to allow for fine tuning once the drone burner is turned on.

[0050] Other self contained direct fired burners can be used if they produce a clean and efficient combustion, so long as the combustion by-products are not incompatible with the process and the personnel involved. A 225,000 BTU venturi burner is not the preferred burner since it does not have a very significant turn down ratio (2:1 vs 40:1 for the nozzle mix burner) and the injected air volume injected is triple the air volume injected by a nozzle mix burner. Multiple venturi style burners which inject heat into the main air stream also can be used. Instead of modulating them, they can be turned on in stages based upon the need for heat which causes a stepped heat rise. The burners may be equal sized, or they may of differing sizes such as, but not limited to, a binary progression.

[0051] System controls can be as simple as a heated replacement air temperature sensor which controls the burner output and a differential pressure sensor to control the speed of the distribution fan. This is typical for a manually controlled system that operated as an air replacement unit which delivers a manually adjusted amount of air into a facility with a general dump distribution head to replace air being exhausted by various devices such as sanding benches, fume hoods, multiple small spray booths and any other process which exhaust air from the facility.

[0052] The system controls also can be a sophisticated software driven, microprocessor based system which monitors and controls a number of primary and ancillary process variables and is programmed to precisely deliver the right volume of clean, conditioned air, at the predetermined temperature. It can respond to the demand to replace the process air being exhausted by the spray booth or any other high volume air exhausting process.

[0053] A key to the efficiency of the system is its ability to vary the airflow through the system without changing the products of combustion. With this capability the spray booth is now able to control the volume and temperature of air being consumed over a wide range based upon the requirements of the process. Temperature conditioning is required on less volume of air and produces significant energy savings. The advances in technology to vary the speed of the fans and the increased cost of fuel have caused the system to become a practical approach to the replacement air process.

[0054] The system can have multiple modes of operation. Either the exhausted air volume or the replacement air volume can be set as the master. The exhaust air volume can be set as the master when the volume can be applied to the process elements which contaminate the air. The replacement air volume can be set as the master maximizing the air flow through the process given the variables in the replacement air system such as outside temperatures and limits in fuel available. This mode causes the exhausted air volume to become slave.

[0055] The most typical operating mode allows the process to dictate the amount of air required. Changes in the volume of air can be triggered by the process variables or in response to the sources that contaminate the air. For example, the exhaust air flow can be increased while coatings are being applied to a workpiece and decreased when the coating operation is stopped or a predetermined time after the coating operation is stopped. Or, the exhaust air flow rate can be controlled in response to the level of VOC's in the spray booth air. While monitoring specific process variables and using these as drivers for safety interlocks and/or as the stimuli to adjust the overall replacement air flow, the system uses these inputs to automatically optimize the performance of the entire system including the process it is serving. The invention focuses upon the requirements of the process with regard to the safe and effective levels for each aspect of the process and develops methods to determine when those processes take place.

[0056] When looking at the painting process, typical modes are idle, prep, low speed paint, high speed paint, low temperature cure, high temperature cure and cool down. The most significant energy savings from the system over prior art systems is in the idle, prep, low speed paint and low temperature cure modes. A focus of the system is to allow a reduction in the total volume of air that is exhausted per day, which in turn reduces the energy needed to heat replacement air.

[0057] The idle mode is used to start the unit and to operate after a low temperature cure. The BTU's of heat delivered to the replacement air may be set, for example, to about 15-25% of the normal operating level. In the prep mode, the BTU's may be adjustable, for example, over a range of 25-40% of the normal operating level, and in the low temperature cure mode the BTU's may be adjustable, for example, in the range of 40-60%. It will be appreciated that the replacement air flow rate and the BTU's applied to the replacement air for different operating modes can be adjusted as needed.

[0058] In any climate that requires temperature or humidity controls, the benefits of the heat injector can be seen. When the cost of replacement air is not a factor due to temperate outside, the system will still have a benefit because the amount of air moved through the system, even without temperature conditioning, will have an affect upon the amount of electrical energy used. In these climates, the addition of an evaporative cooler option might prove to be a benefit. The option to cool the air by utilizing evaporative cooling panels is possible with the reduced static of the system. The same climates that need heat in the winter could use evaporative cooling in the summer. Evaporative cooling coils for dehumidifying and/or cooling the air can be placed immediately after the inlet filters and before the heat injector.

[0059] Commercial benefits of the different embodiments of the invention, provide one or more of the following:

[0060] Only as much make up air is supplied as the process actually needs. The unique design of the system enables it to deliver only as much replacement air as the process is actually discharging. Therefore, a single system can serve a facility equipped with multiple spray booths, economically responding to the varying load as individual spray booths are brought on-line or taken off-line without compromising the system's combustion efficiency of the system and without either over or under ventilating the process.

[0061] Cold start conditions are nearly eliminated. Burner safety regulations require the presence of combustion air before the fuel is turn on. Since traditional direct fired air make-up units use the same air mover to supply both the combustion air and the replacement air, they require a flow of cold air at full volume before the burners can be ignited. When the incoming replacement air temperature is low, this results in significant volumes of uncomfortable cold air being dumped into the process area every time the system is started. To avoid this start-up chill, operating personnel keep their air make-up units operating during down periods, thereby wasting significant quantities of power and fuel. The combustion air, which is typically 10% or less of the replacement air volume, is separate from the replacement air. The primary air mover does not need to be energized until the burner is fired and producing warm replacement air.

[0062] Electrical power consumption is reduced. Since the burners are located outside the primary air passage, the internal pressure drop is a fraction of the pressure drop of a traditional direct fired air make-up unit. The system can deliver a comparable volume of air with significantly less (approximately 30-50% less) horsepower, resulting in a significant savings in electrical power consumption.

[0063] A typical 15,000 CFM prior art air make-up unit requires a 10 HP motor. Due to its unrestricted air passage, a system according to the invention of the same capacity only requires a 5 HP motor to move the air plus a fractional horsepower motor to provide combustion air for each burner. The average annual savings in electrical power due to the reduction in motor horsepower alone can exceed 40%.

[0064] Energy consumption during non-spray operations is significantly reduced. In installations where a single spray booth has a dedicated air make-up unit, the variable volume air supply makes it possible to add a properly sized, variable frequency motor controller to the spray booth's exhaust fan. This allows the entire air replacement/ventilating system to be programmed to exhaust the normal required volume of exhaust air during the spraying and flash-off operations. The exhaust air volume can be stepped down to a substantially lower level during non-regulated activities such as the time when the parts are being prepared for painting, while the paint is being prepared, while the equipment is being set-up or maintained, during break periods and during the cure cycle, thereby achieving significant savings in both electrical power and heating fuel.

[0065] Better temperature control when outside temperatures are moderate: While a traditional constant volume air make-up unit typically includes a modulated gas valve, the inherent design of the air make-up unit does not allow for a good gas flow at low settings. Units sized to provide the typical 70° or 90° F. temperature raise required in colder locations have difficulty maintaining the desired output temperature when the outside temperature is more moderate and the unit has to repeatedly toggle on and off. Consequently, the replacement air tends to be either too hot or too cold. The multiple burner option of the invention and its focus to treat the BTU energy separate from the air volume required for the process allows a better adjustment irrespective of the temperature of the incoming air.

[0066] Coating transfer efficiency can be safely maximized by optimizing air flow for each discrete finishing operation conducted within a spray booth. The system enables the spray booth ventilation to be tuned to safely maximize the overall transfer efficiency for the finishing process. The savings associated with the reduction in coating consumption associated with a 10% increase in the finishing transfer efficiency can conservatively exceed $10,000 per year for each production spray booth.

[0067] The control system for such a system or spray booth system can be equipped with VOC and/or LEL sensors that will automatically increase the exhaust air flow if it detects the higher than desired concentrations of gaseous and/or particulates within the process. When the concentrations decrease or when the finishing process is taken off-line, the exhaust air volume can be automatically reduced.

[0068] Airflow can be optimized at any given temperature setting. When the incoming air temperature drops below its designed temperature rise range, a traditional air make-up unit system will deliver replacement air at a temperature below the desired process set point. Under these circumstances the thermal load of the fixed air delivery volume is beyond the burner's capacity. Users have two options, neither of which is good. They can suspend operations until the outdoor temperature moderates, or they can operate with the process below the desired temperature. The system has the ability to produce the maximum air volume at the set point without compromising the burner's combustion efficiency.

[0069] Some traditional air make-up units are built with a dual air velocity feature to facilitate spraying and curing in a single location. In the spraying mode, the air make-up unit delivers its rated airflow at a predetermined temperature, usually 70° F. In the curing mode, the air flow rate is reduced to a fraction of the spraying, while the temperature set point will be proportionally higher, typically in the 125-150° F. range. The clean burn characteristics are lost at this point because the required airflow across the burner has been significantly reduced. A colder than normal ambient temperature can also be a problem in the curing mode even with the reduced air flow. The unit may have enough capacity for the painting process, but not enough capacity to achieve the desired cure temperature. The system can be programmed to reduce the airflow to a level within the unit's capacity to achieve the programmed cure temperature within the process area. Again, this can be done without jeopardizing the minimum airflow requirements of the burner.

[0070] The system's variable volume capability enables it to handle these out of tolerance situations well and provides process advantages that are not currently available. The system gives the operator the ability to control the curing cycle by further turning up the thermostat set point and simultaneously lowering the volume of process air or increasing the airflow at a reduced set point. The system provides the optimum control for flashing off and then curing sensitive waterborne coatings.

[0071] The design can facilitate automatic conversion between direct and indirect heat transfer. The system is ideally suited to processes that require large volumes of heated replacement air at times and require an indirect air heater recirculated heat source at other times. A typical application would be a plant or lab area with open face spray booths. In this situation, the direct fired burner is used when the outside replacement air is required and the indirect fired unit is used when the exhaust dampers close to recycle the exhaust air within the process.

[0072] This unit also can be used in a continual state as a recirculated burner. It can be configured to operate in a direct fired mode allowing the process area to be quickly and efficiently heated, then, when the area is nearly up to temperature and the burner is normally turned down, the system is switched to the indirect fired mode to isolate the process area from the buildup of harmful by-products of combustion.

[0073] The system allows the process area to be brought up to temperature quickly by utilizing the high efficiency and the clean burn of the direct fired burner at its normal high gas flow. Once the space has reached the desired temperature, the burner controls can be programmed to be automatically turned down to reduce the air flow, and to automatically convert to an indirect heat source to maintain the temperature by injecting the heat into the process through a heat exchanger. This will prevent injecting any harmful combustion by-products at the lower burner levels. This capability provides the advantages of both a direct and an indirect fired burner, while eliminating the disadvantages of each. The system's dual-mode option provides significant energy efficiency gains and eliminates the need to purchase dual heating systems with the expense of multiple building penetrations and gas lines.

[0074] The indirect option also allows the system to be used as a post-heater in a humidity controlled system. When humidity control is required, the system in the indirect heating mode can be added downstream of the cooling coils to act as a post-heater to bring the super chilled air back to the desired temperature set point. In the indirect heat mode, the burner combustion byproduct gases are isolated from the process air stream and cannot add moisture to it.

[0075] During the heating season, the system operates in the direct fired mode. This is the most energy efficient mode and the direct fired combustion will increase the process air's humidity, reducing the amount of additional moisture required to bring it up to the required relative humidity level. The direct fired burner can be downstream of the cooling coils because any escaped gas from the cooling coils will not be exposed to the burner flame.

[0076] Overall reduction in capital costs: The system is significantly lighter than the comparable air make-up unit it replaces. Typically the electric motor is half the horsepower size of that of an equivalent sized traditional unit. The air supply fan is correspondingly smaller than the traditional air make-up unit. The substantial weight of the traditional air make-up unit often requires the construction and installation of a costly steel reinforced supporting structure.

[0077] The modular nature of the system allows the replacement air unit to be broken into segments to provide greater flexibility in where components are located and sometimes in eliminating the need to have an expensive crane to set it in place. This flexibility can also simplify ductwork as well as make it more convenient to service.

[0078] Modularity facilitates combining with other process air condition technologies: The modular design of the system is adaptable for use with a variety of heat sources such as steam and the heat thrown off by environmental emissions abatement systems and thermal oxidizers. Heated air from these sources of energy can be injected into the air stream as the only source of BTU energy, or to augment a gas fired burner. Since the heat source is not in the middle of the air stream, the system can safely and easily be coupled with an evaporative cooler, a dehumidification chiller or any other air conditioning device or system.

[0079] It will be appreciated that various modifications and changes may be made to the above described preferred embodiment of a heated replacement air system without departing from the scope of the following claims.

What is claimed is:

1. An apparatus for supplying heated replacement air to a process in which air is exhausted, the apparatus comprising:

an air intake connected to an injection chamber from which an adjustable volume of replacement air flows to the process,

a source of BTU energy positioned outside and connected to the injection chamber and configured to inject heated gas into the injection chamber, wherein the adjustable volume of air through the injection chamber can change without affecting the air-to-fuel ratio of said source of BTU energy; and,

at least one process fan configured to:

i) draw the replacement air through the air intake and into the injection chamber based upon the variable requirements of the process, and

ii) deliver a predetermined and adjustable volume of the heated replacement air to the process

2. The apparatus for supplying heated replacement air to a process, as set forth in claim **1**, further including a mixing device located between the injection chamber and the at least one fan.

3. The apparatus for supplying heated replacement air to a process as set forth in claim **1**, wherein the source of heated gas is a gas burner positioned outside the injection chamber, the gas burner including a dedicated blower connected to the gas burner to supply the combustion air and inject heated gases from the gas burner into the injection chamber.

4. The apparatus for supplying heated replacement air to a process, as set forth in claim **1**, further including an adjustable mode changing damper configured to be moveable between a first position, wherein replacement air from a first location is drawn by the at least one fan from the air intake into the injection chamber, and a second position, wherein air from a second location is drawn by the at least one fan into the injection chamber.

5. An apparatus for supplying heated replacement air to a process in which air is exhausted, the apparatus comprising:
- an air intake connected to an injection chamber for supplying a desired volume of replacement air to the process;
- a source of BTU energy positioned outside and connected to said injection chamber and configured to inject heated gas into said injection chamber;
- at least one delivery fan configured to:
  - i) draw replacement air through the air intake and into said injection chamber,
  - ii) mix the heated gas with the replacement air to form the heated replacement air, and,
  - iii) deliver a predetermined adjustable volume of the heated replacement air to the process,
- wherein the volume of the heated replacement air is substantially the same volume as the exhaust air from the process, and wherein the volume of the replacement air does not affect the air-to-fuel ratio of the BTU energy that is injected into said injection chamber.

6. The apparatus for supplying heated replacement air to a process, as set forth in claim **5**, and further including multiple gas burners positioned outside the injection chamber wherein the gas burners would each have a dedicated blower with the gas burners having the same or different BTU output with controls to engage the gas burners adjust the injected BTU energy.

7. The apparatus for supplying heated replacement air to a process, as set forth in claim **5**, and further including an indirect heat exchanger mounted in the injection chamber configured to be moveable between first and second positions during the operation of the apparatus,
- wherein when the indirect heat exchanger is in the first position heated gas is injected directly into replacement air drawn through the injection chamber; and,
- wherein when the indirect heat exchanger is in the second position heated gas flows through the indirect heat exchanger and out through a vent in the apparatus which is engaged as the indirect heat exchanger is moved into the second position and replacement air drawn through the injection chamber is indirectly heated by the indirect heat exchanger.

8. The apparatus for supplying heated replacement air to a process, as set forth in claim **7**, and further including an adjustable intake damper mounted between the air intake and the injection chamber; the adjustable intake damper having a position permitting an unrestricted flow of air from the first location through the air intake when the indirect heat exchanger is in its first position and the intake damper blocking air flow from the first location through the air intake when the indirect heat exchanger is in its second position to force the flow of air from a second location.

9. The apparatus for supplying heated replacement air to a process, as set forth in claim **5**, wherein the source of BTU energy is a gas burner, the gas burner including a dedicated blower connected to develop a proper air-to-fuel ratio and inject hot combustion gases from the gas burner into the injection chamber thereby preventing a change in the volume of replacement air from directly affecting the air-to-fuel ratio in said gas burner.

10. The apparatus for supplying either direct heated replacement air to a process or indirect heated air as set forth in claim **5**, the apparatus further including:
- a mode changing damper having a first position, wherein replacement air from a first location is drawn by the at least one fan from the air intake into the injection chamber, and having a second position,
- wherein air from a second location is drawn by the at least one fan into the injection chamber across a movable indirect heat exchanger mounted in the injection chamber,
  - the indirect heat exchanger being in the first position when the damper is in the first position and heated gas is injected directly into replacement air drawn through the injection chamber; and,
  - the indirect heat exchanger being in the second position when the damper is in the second position and heated gas flows through the indirect heat exchanger and replacement air is drawn through the injection chamber and is indirectly heated by the indirect heat exchanger.

11. A method for providing heated replacement air to a process in which air is exhausted comprising the steps of:
- a) drawing an adjustable volume of replacement air through an air intake and an injection chamber;
- b) injecting a flow of hot gas from a BTU source located outside the injection chamber into the replacement air as it is drawn through said injection chamber to heat the replacement air to the desired temperature where the injected hot gas is produced with an optimum air-to-fuel ratio not affected by changes in the replacement air volume, and,
- c) mixing the replacement air and the injected hot gas to provide a substantially uniform temperature to the heated replacement air.

12. The method for providing heated replacement air at variable air volumes to a process, as set forth in claim **11**, and further including the steps of:
- d) sensing the temperature of the heated replacement air after it is mixed; and,
- e) adjusting the BTU's output in the injected flow of hot gas to maintain a desired temperature in the heated replacement air delivered at different air volumes to the process.

13. The method for providing heated replacement air to a process at variable air volumes, as set forth in claim **12**, and further including the steps of:
- adjusting a flow of replacement air delivered to the process in response to changes in the amount of air exhausted from the process; and
- adjusting the BTU's in the flow of hot gas injected into the injection chamber by the engagement of a plurality of burners with the same or differing output levels where the burners would be located outside the injection chamber and each burner would have a dedicated blower to produce a BTU output at an optimal air-to-fuel ratio where the burners are engaged to maintain a desired temperature in the heated replacement air.

14. The method for providing heated replacement air to a process, as set forth in claim **12**, including converting from directly heating replacement air to indirectly heating replacement air with the use of a mode changing damper and a moveable heat exchanger in the injection chamber, injecting the hot gas into the heat exchanger, and heating the replacement air with the heat exchanger.

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