

A MULTI-INTERFACE UNIT INVIGORATION SYSTEM AND METHOD OF USE**FIELD OF THE INVENTION**

The present invention relates to aeration. More specifically, the present invention relates to modified modes of local aeration and ventilation where simultaneous invigoration and cooling are required.

BACKGROUND OF THE INVENTION

Conventional cooling methodologies, based on a closed refrigeration cycle, are not always suitable for field conditions or huge spaces, where only specific zones require concentrated local cooling or pulsating cooling. For this reason, invigoration associated with simultaneous cooling is a common desire and a great necessity in a wide variety of applications, where local concentrated cooling and pulse cooling are needed.

A typical well-known need for health refreshment and air supply of spaces is the ventilation of large commercial or industrial buildings, underground spaces, spaces in field conditions (such as military installations), greenhouses - where the forced air flow is not effective in treating the problems of internal temperature regulation, moisture accumulation and impurities and/or infections which can accumulate over time. In fact, internal or external forced ventilation results in poor air quality with several types of health difficulties, and at the same time consume a high cost of mechanical energy.

It should be noted that mechanical ventilation is mainly used for forced air flow in order to prevent the accumulation of heat and humidity. That is, circulation by itself does not guarantee the quality of the air or the internal climate desired for residents or nutrition spaces.

Moreover, since industrial or commercial buildings are particularly associated with extremely large volumes, forced ventilation throughout the vast space is ineffective.

Cooling using compressed air expansion is mainly known in the field of CAES-compress energy storage or in risk cases such as nuclear reactors described in CN104534601A1 and US 20160097552A1. In most situations, or almost all related cases, one-stroke expansion, or full expansion of stored compressed air is referred to. Obviously, such situations require recompression followed by dissipation of the compression heat and storage for the next use. Such a mode of operation requires a problematic cooling phase associated with a time delay between successive uses.

US1879685 and JPH01107029A offer continuous compression in parallel with continuous cooling to deal with the continuous compression heat generated. Such an approach involves rather complicated cooling systems to ensure continuous dissipation of the heat of compression. It should also be mentioned that DE102011050691A1 and KR20170076892A utilize compressed air expansion in air conditioning or humidity control systems.

It is an aim of the present invention to provide an economical local invigoration cooling aeration system that focuses on locally focused cooling with continuous or discontinuous controlled modes of operations.

SUMMARY OF THE INVENTION

The term invigoration in the present invention refers to simultaneous aeration or refreshing accompanied by cooling and optional gas enrichment and purification as needed.

In fact, conventional air cooling methodologies, based on a closed refrigeration cycle, are not always suitable for field conditions or huge spaces, where only specific spots are to be treated by concentrated cooling, pulsating cooling, and the like. For this reason, invigoration associated with simultaneous cooling is a common desire and a great necessity in a wide spectrum of applications where closed refrigeration cycle is not applicable.

The present invention is of an invigoration cooling aeration system.

The advantage of the system of the present invention is multiple:

- (a) the system can be used to cool and or invigorate particular zones in large spaces such as commercial or industrial spaces, greenhouses, etc.
- (b) the system can be used for concentrated local cooling.
- (c) the system can be used for continuous cooling/pulse cooling. The system controls the sequence and intensity of the pulses. Non-continuous cooling or local spot cooling of defined parts of the entire space may be used in order to ensure optimal nourishment to maintain the quality of the products or the health of the occupants. Included in this category are targeted cooling of specific local areas such as areas of electronic components, immediate rapid cooling, periodic cooling as in medicine, etc.
- (d) the system can be used for direct cooling of multiple components, which require simultaneous temperature management each at different temperature level or fast removing of local heat dissipation.
- (e) the system is highly economical as it uses gas expansion for cooling purposes, thus, saving energy.

(f) the system may be used as portable device in the above-mentioned applications or others.

In accordance with some embodiments of the present invention, there is thus provided a multi-interface unit invigoration system for providing invigoration and/or cooling via continuous or noncontinuous controlled modes of operation. The system comprising:

either concentric or non-concentric multiple interface units, said multiple interface units are programed to provide gas either to a predefined spot/volume or to multiple spots/volumes, either continuously or by at least one predefined time sequence,
at least one compressed gas source for providing compressed gas to at least one of said multiple interface units,
a controller,

wherein to ensure effective and well-controlled cooling, the compressed gas is maintained at a predefined temperature, in each of said multiple interface units, wherein each of said multiple interface units is programmed to receive said compressed gas and to expand said compressed gas continuously or via at least one predefined time sequence to control the temperature of each of said multiple interface units,

whereby the multi-interface unit invigoration system providing invigoration and/or cooling with either continuous or noncontinuous controlled modes of operation.

Furthermore, in accordance with some embodiments of the present invention, the multiple interface units are arranged either in parallel or in a consecutive manner.

Furthermore, in accordance with some embodiments of the present invention, the compressed gas is selected from air, Nitrogen, Carbon dioxide, Ozone (O₃), and Oxygen (O₂).

Furthermore, in accordance with some embodiments of the present invention, in case said multiple interface units are arranged in a consecutive manner, the compressed gas is transferable from each of said multiple interface units to a consecutive receiving interface unit, thus, gas expansion associated with cooling in each of said multiple interface units leading to gas compression associated with heating in said consecutive receiving interface unit.

Furthermore, in accordance with some embodiments of the present invention, in case said multiple interface units are arranged in parallel, gas compression into each of said multiple interface units and/or gas expansion from each of said multiple interface units is either continuous or activated by at least one predefined time sequence.

Furthermore, in accordance with some embodiments of the present invention, the

temperature of the gas being discharged from each of said multiple interface units is controlled by a mode of operation, either a continuous mode of operation or a non-continuous mode of operation set by at least one predefined time sequence of said gas compression and said gas expansion in each of said multiple interface units.

Furthermore, in accordance with some embodiments of the present invention, in said non-continuous mode of operation, the gas expansion and the gas compression take place interchangeably at predefined times in each of said multiple interface units.

Furthermore, in accordance with some embodiments of the present invention, the at least one compressed gas source is a compressor.

Furthermore, in accordance with some embodiments of the present invention, the at least one compressed gas source is a vessel containing compressed gas.

Furthermore, in accordance with some embodiments of the present invention, the multi-interface unit invigoration system further comprising at least one pressure vessel.

Furthermore, in accordance with some embodiments of the present invention, each of the multiple interface units comprises a discharge device.

Furthermore, in accordance with some embodiments of the present invention, the discharge device is selected from a moderate controlled quasi-reversible discharge device, a nozzle discharge device, an instantaneous prompt solenoid discharge device, and a turbine.

Furthermore, in accordance with some embodiments of the present invention, the instantaneous discharge device is a solenoid valve.

Furthermore, in accordance with some embodiments of the present invention, the multi-interface unit invigoration system further comprising a gas enrichment sub-unit (GEU), said gas enrichment sub-unit (GEU) providing an enriching gas stream connected to at least one gas stream discharged from at least one of said multiple interface units to enrich said at least one gas stream being discharged from the at least one of said multiple interface units.

Furthermore, in accordance with some embodiments of the present invention, the multi-interface unit invigoration system further comprising a purifying gas stream discharge unit for providing a purifying gas stream.

Furthermore, in accordance with some embodiments of the present invention, the purifying gas stream is connected to the enriching gas stream provided to at least one of said multiple interface units to purify said gas stream.

Furthermore, in accordance with some embodiments of the present invention, the enriching gas and/or the purifying gas is selected from air, Nitrogen, Carbon dioxide, Ozone (O₃), and Oxygen (O₂).

Furthermore, in accordance with some embodiments of the present invention, when an expansion phase in one interface unit comes to an end, a consecutive interface unit goes into its expansion phase, while recompression begins in the one interface unit, and when the consecutive interface unit completes its expansion phase, it is recompressed, while the following interface unit goes into its expansion phase.

Furthermore, in accordance with some embodiments of the present invention, each one of the interface units operates in a mode selected from light or immediate ventilation mode, ventilation with cooling mode, and aeration mode with or without disinfection.

Furthermore, in accordance with some embodiments of the present invention, the multi-interface unit invigoration system further comprising an intermediate collection vessel, wherein each of the multiple interface units is drained into said intermediate collection vessel, wherefrom invigorating gas is supplied.

Furthermore, in accordance with some embodiments of the present invention, the multi-interface unit invigoration system further comprising a pressurized vessel for indirect charging of the multiple interface units, said pressurized vessel is charged with compressed gas via said at least one compressed gas source and is maintained at high pressure, said pressurized vessel is connected to each of the multiple interface units for charging each of the interface units with compressed gas either continuously or via at least one pre-defined time sequence.

Furthermore, in accordance with some embodiments of the present invention, said multiple interface units have multiple volumes.

Furthermore, in accordance with some embodiments of the present invention, said multiple interface units having multiple volumes are arranged by volume.

Furthermore, in accordance with some embodiments of the present invention, small volume interface unit(s), medium volume interface unit(s), and large volume interface unit(s) are arranged in a successive manner, wherein one of the small volume interface unit(s) is a charging high pressure interface unit, and wherein an expansion phase starts from a high pressure level in the charging high pressure small interface unit and continues successively to a lower pressure level in the large volume interface unit(s).

Furthermore, in accordance with some embodiments of the present invention, large volume interface unit(s), medium volume interface unit(s), and small volume interface unit(s) are arranged in a successive manner, wherein one of the large volume interface unit(s) is a charging high pressure interface unit, and wherein an expansion phase starts from a high

pressure level in the large charging high pressure interface unit and continues successively to a lower pressure level in the small volume interface unit(s).

Furthermore, in accordance with some embodiments of the present invention, said small volume interface unit(s) is situated in said medium volume interface unit(s), and said medium volume interface(s) unit is situated in said large volume interface unit(s) to have a direct heat transfer, to cool each other while the compressed gas in each of said interface units undergoes an expansion phase.

Furthermore, in accordance with some embodiments of the present invention, said multi-interface unit invigoration system is a non-concentric multi storage unit, where expansion and cooling occur in each of the interface units due to generation of local Venturi effect due to local variations in the path of the gas stream within each of the interface unit.

Furthermore, in accordance with some embodiments of the present invention, a local expansion in each of said interface units is determined by the eccentricity of the non-concentric interface unit.

Furthermore, in accordance with some embodiments of the present invention, a flow reversal in each of the interface units, and a local turbulence of the gas flow, induce temperature reduction.

Furthermore, in accordance with some embodiments of the present invention, the gas is accelerated by entering through at least one narrow gap into the non-concentric interface unit, and then, the gas expanding immediately upon exiting the non-concentric interface unit through at least one wide gap.

Furthermore, in accordance with some embodiments of the present invention, a gas flow reversal and local turbulence causing a temperature drop.

Furthermore, in accordance with some embodiments of the present invention, the multi-interface unit invigoration system is pre-programmed to operate in a continuous mode, providing gas streams at various levels of cooling and cooling capabilities.

Furthermore, in accordance with some embodiments of the present invention, there is thus provided a multi-interface unit invigoration method. The method comprising:

- providing the described above multi-interface unit invigoration system;
- arranging said concentric or non-concentric multiple interface units,
- programming said concentric or non-concentric multiple interface units to provide compressed gas either to a predefined spot/volume or to multiple spots/volumes,

- to ensure effective and well-controlled cooling, maintaining the compressed gas at a predefined temperature, in each of said multiple concentric or non-concentric interface units;
- programming each of said concentric or non-concentric multiple interface units to receive said compressed gas and to expand said compressed gas continuously or via at least one predefined time sequence to control the temperature of each of said concentric or non-concentric multiple interface units.

Furthermore, in accordance with some embodiments of the present invention, the method further comprising connecting said concentric or non-concentric multiple interface units in a consecutive manner, so that expansion associated with cooling in one concentric or non-concentric interface unit leading to compression associated with heating in a consecutive concentric or non-concentric interface unit.

Furthermore, in accordance with some embodiments of the present invention, further comprising inducing a time delay between a compression phase and an expansion phase in each of said concentric or non-concentric multiple interface units for controlling the temperature in each of said multiple consecutive concentric or non-concentric interface units.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 (PRIOR ART) illustrates a conventional aeration system available today.

Fig. 2 illustrates a first invigoration system in accordance with some embodiments of the present invention.

Fig. 3A illustrates a first configuration of a single interface unit, a moderate quasi-reversible discharge interface unit in accordance with some embodiments of the present invention.

Fig. 3B illustrates a second configuration of a single interface unit, a nozzle discharge interface unit, in accordance with some embodiments of the present invention.

Fig. 3C illustrates a third configuration of a single interface unit, an instantaneous discharge interface unit in accordance with some embodiments of the present invention.

Fig. 3D illustrates a fourth configuration of a single interface unit, an aeration unit comprised of a turbine interface unit in accordance with some embodiments of the present invention.

Fig. 4A illustrates an invigoration system using an annular cooling configuration of compressed gas in accordance with some embodiments of the present invention.

Fig. 4B illustrates an invigoration system using an internal cooling configuration of compressed gas in accordance with some embodiments of the present invention.

Fig. 5 illustrates an assembly of multi-interface unit invigoration system in parallel in accordance with some embodiments of the present invention.

Fig. 6 illustrates an assembly of multi-interface units invigoration system for continuous discharge in accordance with some embodiments of the present invention, including gas enrichment sub-system.

Fig. 7 illustrates an assembly of multi-interface units based on indirect charging invigoration system for local invigoration in accordance with some embodiments of the present invention.

Fig. 8 illustrates a comprehensive assembly for timewise and a spot wise invigoration in accordance with some embodiments of the present invention.

Fig. 9A illustrates a multi storage unit in series, of low pressure discharge assembly in accordance with some embodiments of the present invention.

Fig. 9B illustrates a multi storage unit in series, high pressure discharge assembly in accordance with some embodiments of the present invention.

Fig. 10A illustrates a compact multi-stage unit inner to exterior assembly 1000 in accordance with some embodiments of the present invention.

Fig. 10B illustrates a compact multi-stage unit exterior to inner assembly 1050 in accordance with some embodiments of the present invention.

Fig. 10C illustrates an alternative multi-stage non-concentric inner to exterior assembly in accordance with some embodiments of the present invention.

Fig. 10D illustrates an alternative multi-stage non-concentric exterior to inner assembly in accordance with some embodiments of the present invention.

Fig. 11 shows a multi-interface unit of the present invention used to supply fresh air in conjunction with the main air conditioning system.

Fig. 12A is a flow diagram of the multi-interface unit invigoration system of the present invention and Fig. 12B shows the actual multi-interface unit invigoration used for conducting the experiments.

Fig. 13 illustrates the temperature drop of discharge unit 1204A at a discharge Pressure of 8 bar and pre-cooling.

Fig. 14A is a graph of temperature drop versus pressure discharge, with pre-cooling.

Fig. 14B is a graph of temperature drop versus discharge pressure, with pre-cooling.

Fig. 15A is a graph illustrating the heating rate of the charging reservoir due to gradual recharge.

Fig. 15B is a graph illustrating the temperature drop of the charging reservoir.

Fig. 16 refers to the heating rate of the discharge unit due to indirect charging by the charging reservoir, with or without a pre-cooling step.

Fig. 17A shows the temperature drop for various pressure ranges with the precooling step, utilizing indirect charging.

Fig. 17B represents a comparison of the temperature drop with or without precooling phase, utilizing indirect charging.

Fig. 18 refers to alternating discharge of the two discharge units.

Fig. 19 represents a fairly automatic continuous alternating discharge of the two discharge units at 8 bar.

Fig. 20 illustrates a continuous process of simultaneous charging and discharging at 8 bar.

Fig. 21 represents continuous simultaneous charging and discharging as in Fig. 20, with the distinction that the valve between the charging reservoir and the discharging unit is shut down during the discharging process.

DETAILED DESCRIPTION OF THE FIGURES

In what follows, the invention will be demonstrated and understood from the following drawings. Embodiments, features and aspects of the invention are described herein in conjunction with the following drawings.

It is to be noted at this point, that all drawings are meant to be descriptive but not limiting. Although particular embodiments include some details, for the sake of illustration, various alternative modifications may be considered, without departing from the principles of the invention.

The reference numbers in the drawings are used to point out some elements in the embodiments, in order to facilitate the understanding of the invention principles, and as such they are merely illustrative and not limiting.

In accordance with some embodiments of the present invention, the invigoration system of the present invention uses gas, such as air, Nitrogen, Carbon dioxide, Ozone (O₃), Oxygen (O₂) and the like for ventilation, aeration, sterilization and the like.

In accordance with some embodiments of the present invention, gas is hereinafter referred to as "air".

Fig. 1 (PRIOR ART) illustrates a conventional forced aeration system 100 commonly available today.

As can be seen in the figure, conventional forced ventilation system 100 is used for invigorating an internal space 101 which may be a large space, commercial or industrial building, space of food storage, agricultural greenhouse and the like.

Conventional ventilation systems available today such as the conventional ventilation system 100 seen in the figure are based on an intensive air circulation that can be achieved by a set of compressors 102A-102F, which push air from the outside directly into the interior of the space (in some cases, the indoor air itself is circulated through the entire volume without any exchange with the outside). Such typical systems make it difficult or even impossible to control the climate or humidity, while simultaneously encouraging the migration of contaminants throughout the space.

Unlike the above-described conventional forced ventilation system 100, the basic approach of the present invention is to use compressors to first build a reservoir of compressed air, from which rapid expansion takes place at the required time and place.

The compressed air that expands into the space may be dry and purified as needed and getting cooled as expands.

Fig. 2 illustrates a first invigoration system 200 in accordance with some embodiments of the present invention. The first invigoration system 200 comprises multiple compressors used to build reservoirs.

As can be seen in the figure, the first invigoration system 200 may comprise several compressors, such as compressors 202A-C connected to reservoirs, such as reservoirs 204A-C that provide compressed air in several locations of the large space 206. Alternatively, at least one compressor such as compressor 202D may be connected to a single central reservoir 204D that supplies compressed air to the entire large space 206.

It is clear that Fig. 2 represents a general alignment only, while the effective operation to achieve an optimal invigoration depends on the interface between the compressed air reservoir and the space being treated.

The proper design of the interface unit in accordance with some embodiments of the present invention provides parameters of the optimal local invigoration, cooling, and aeration/ventilation.

The interface unit may be an external, independent stand-alone assembly, that can easily be placed remotely from the compressor and close to the area intended for treatment. As will be detailed below, the interface unit may include safety and control measures to manage and control the mode of operation at the place and time as pre-programmed by the user.

In accordance with some embodiments of the present invention, the functional characteristics of the interface unit may be determined by its discharge mode according to the discharge device used. The gas enrichment sub-unit, GEU, can be coupled with the cold stream discharge unit to provide simultaneous gas replenishment or purification features within its modes of operation.

In accordance with some embodiments of the present invention, the enriching gas and/or the cold gas is selected from air, Nitrogen, Carbon dioxide, Ozone (O₃), Oxygen (O₂) and the like. In accordance with some embodiments of the present invention, different discharge modes may be used, depending on the particular application in question, specifically, depending on the desired exit temperature and consequently the associated cooling effect. For example, when searching for an optimal reinforcement scheme for a complicated space of non-uniform local demands, a multi-unit system of spot wise local discharge may be adjusted effectively.

In accordance with some embodiments of the present invention, any of the schemes illustrated and described in Figs. 3A-10D may be effectively adapted to address the specific nature of local invigoration needs, namely: simple local aeration and refreshment, air disinfection, oxygenation or any gas enrichment, with or without cooling effects and the like.

According to some embodiments of the present invention, non-continuous treatment or spot wise treatment of defined areas/volumes may be preferable in numerous fields to ensure the quality of the products or the health of the occupants. For example, in electronics, targeted cooling of specific small areas of electronic components is common, and rapid instantaneous cooling and/or discontinuous cooling are usually needed in medical procedures.

In accordance with some embodiments of the present invention, the discharge modes described below can be designed as mobile units to address the above-mentioned applications and the like.

Fig. 3A illustrates a first configuration of a single interface unit, a moderate quasi-reversible discharge interface unit 300 in accordance with some embodiments of the present invention.

As seen in the figure, the moderate quasi-reversible discharge interface unit 300 may comprise a pressurized vessel 302 fed by at least one compressor such as a central compressor 304 to a predetermined desired pressure, and a moderate quasi-reversible discharge device 306.

The moderate quasi-reversible discharge interface unit 300 may further comprise a gas enrichment sub-unit (GEU) 308 connected to the cold gas stream discharged from quasi-reversible discharge device 306.

The gas enrichment sub-unit 308 may be directed to enrich the discharged air from quasi-reversible discharge device 306 by N₂, O₂, CO₂ and the like or purifying gas as ozone.

The gas enrichment sub-unit 308 may be connected to a purifying gas stream exiting from discharge unit 310 to provide simultaneous gas filling or purification within its operating modes.

In accordance with some embodiments of the present invention, the gas enrichment sub-unit 308 may be integrated to any of the interface units demonstrated below.

Fig. 3B illustrates a second configuration of a single interface unit, a nozzle discharge interface unit 320 in accordance with some embodiments of the present invention.

As seen in the figure, the nozzle discharge interface unit 320 may comprise a pressurized vessel 322 fed by at least one compressor such as a central compressor 324 to a predetermined desired pressure, and nozzle discharge device 326.

The nozzle discharge interface unit 320 may further comprise a gas enrichment sub-unit (GEU) (not seen in the figure) connected to the cold gas stream discharged from the nozzle discharge device 326. The gas enrichment sub-unit may be directed to renew the discharged air. The gas enrichment sub-unit may be connected to a purifying gas stream exiting from discharge unit (not seen in the figure) to provide simultaneous gas filling or purification within its operating modes.

Fig. 3C illustrates a third configuration of a single interface unit, an instantaneous discharge interface unit 340 in accordance with some embodiments of the present invention.

As seen in the figure, the instantaneous discharge interface unit 340 may comprise a pressurized vessel 342 fed by the at least one compressor such as the central compressor 344 to a predetermined desired pressure, and an instantaneous discharge device such as an instantaneous prompt solenoid discharge device 346.

The instantaneous discharge interface unit 340 may further comprise a gas enrichment sub-unit (GEU) (not seen in the figure) connected to the cold gas stream discharged from the instantaneous discharge interface unit 340. The gas enrichment sub-unit may be directed to renew the discharged air. The gas enrichment sub-unit may be connected to a purifying gas stream exiting from discharge unit (not seen in the figure) to provide simultaneous gas filling or purification within its operating modes.

Fig. 3D illustrates a fourth configuration of a single interface unit, an aeration unit comprised of a turbine interface unit 360 in accordance with some embodiments of the present invention.

As seen in the figure, the aeration unit comprised of a turbine interface unit 360 may comprise a pressurized vessel 362 fed by at least one compressor such as the central compressor 364 to a predetermined desired pressure, and a turbine 366 to discharge the air.

The aeration unit comprised of a turbine interface unit 360 may further comprise a gas enrichment sub-unit (GEU) (not seen in the figure) connected to the cold gas stream discharged from the instantaneous discharge interface unit 340. The gas enrichment sub-unit may be directed to renew the discharged air. The gas enrichment sub-unit may be connected to a purifying gas stream exiting from discharge unit (not seen in the figure) to provide simultaneous gas filling or purification within its operating modes.

It should be emphasized at this point that according to the present invention, the compressors used in Figs. 3A-D can be replaced by a higher pressure charging reservoir in which case the charging energy as well as the heating rate due to charging are significantly lower than by direct compression.

Each of the interface units shown in Figs. 3A-3D comprises a discharge device whose purpose is to produce work or high kinetic energy from the gas that expands under pressure at the expense of the internal energy and thus affects a decrease in the temperature of the gas. A similar effect can be achieved by allowing the gas to expand into an elastic vessel which exerts considerable resistance against the expanding gas, again at the expense of its internal energy from the expanding gas under pressure.

However, the interface unit of Fig. 3D that includes a turbine to utilize the internal energy of the expanding gas is advantageous since the work produced can be used, for example, to operate additional components such as a blower essential for causing a local flow of the discharged invigorating stream.

In accordance with some embodiments of the present invention, the various interface units described above determine the discharge modes desired by the user according to the ultimate goal of the invigoration, whether it is aimed for moderate ventilation, cold ventilation, aeration, overall temperature regulation, gas enrichment, disinfection refresh and the like.

In accordance with some of the embodiments of the present invention, the discharge from each unit of Figs. 3A-D may be branched into multiple locations/uses as needed. For instance, the decrease in outlet temperature turns the moisture of the water into a liquid and thus allows water to be removed for reuse.

As we know for instance, humidity is the most problematic for plants. Indeed, most growers are working to incorporate dehumidification technologies in order to reduce humidity. The technologies presented here are all related to temperature drop, dry air and a by-product of water. In accordance with some embodiments of the present invention, the analysis of the units shown and described in Figs. 3A-D points out that in order to ensure effective and well-controlled cooling, the initial gas temperature before the expansion should be maintained at a

predefined temperature, for instance room temperature. In practice, this may be possible in two ways:

- (a) by including simultaneous cooling of the interface unit as shown in Figs. 4A-B.
- (b) by inducing a time delay between the compression phase and the expansion phase. The time delay is determined by the cycle of the interface unit as pre-programmed by the user. Therefore, as described above, the stimulation processes may be continuous as in (a) or discontinuous as in (b) depending on the specific application.

In accordance with some embodiments of the present invention, an invigoration cycle may comprise the following timewise stages:

- Stage I: at time $t=0$, the pressure in the pressurized container (interface unit) is P_i and its temperature may be predefined, for instance, room temperature due to cooling.
- Stage II: when expansion is initiated, for instance, by one of the modes illustrated in Figs. 3A-D, e.g., by a moderate controlled quasi-reversible discharge device 306, nozzle discharge device 326, an instantaneous prompt solenoid discharge device 346 such as a solenoid valve, or a turbine 366, at least one of the invigoration modes described above occurs, namely at least one of fresh dry ventilation, cold aeration, disinfecting ventilation, and the like.
- Stage III: at the end of stage II, recompression of the gas in the interface unit begins while the interface unit is being refilled with compressed air, and ending at the required operating pressure, P_i .
- Stage IV: cooling the compressed air, for example, by one of the cooling modes illustrated and described below in Figs. 4A-B.

At the end of the cooling phase, the temperature of the compressed air is reduced back to a predefined temperature by dissipating the heat of compression.

Fig. 4A illustrates an invigoration system using an annular cooling configuration of compressed air 400 in accordance with some embodiments of the present invention.

As seen in the figure, the invigoration system using annular cooling configuration of compressed air 400 may comprise cooling means to cool a pressurized interface unit 402. As can be seen in the figure, the pressurized interface unit 402 may be situated within an outer vessel 404 filled with coolant such as water to cool the pressurized interface unit 402. The pressurized interface unit 402 may be fed by at least one compressor such as a central compressor 406 to a predetermined desired pressure.

As can be seen in the figure, the invigoration system using annular cooling configuration of compressed air 400 may further comprise a gas enrichment sub-unit (GEU) 408 and an

additional purification unit 410 whose goal is to effectively reach the required purification level.

The gas enrichment sub-unit, GEU 408 may be directed to feed the air discharged from the pressurized interface unit 402.

The gas enrichment sub-unit 408 may be connected to a purifying gas stream exiting from discharge unit 410 to provide simultaneous gas feeding or purification within its operating modes.

Fig. 4B illustrates an invigoration system using an internal cooling configuration of compressed air 450 in accordance with some embodiments of the present invention.

As seen in the figure, the invigoration system using an annular cooling configuration of compressed air 450 may comprise a pressurized interface unit 452 equipped with cooling means such as at least one internal cooling coil 454. The pressurized vessel 452 may be fed by at least one compressor such as a central compressor 456 to a predetermined desired pressure.

As can be seen in the figure, the invigoration system using an annular cooling configuration of compressed air 450 may further comprise a gas enrichment sub-unit (GEU) 458 and a specifically purifying stream discharge unit 460. The gas enrichment sub-unit, GEU 458 may be directed to feed the air discharged from the pressurized interface unit 452.

A stream of the gas enrichment sub-unit, GEU 458 may be connected to a stream of the purifying stream discharge unit 460 prior to connecting to the gas stream discharged from the pressurized interface unit 452 to enrich and disinfect the gas stream, and thus, to provide simultaneous gas feeding or purification within its operating modes.

Thus, according to some embodiments of the present invention, dissipation of compression heat may be accomplished by various ways, for instance, as described above in Figs. 4A and 4B via simultaneous cooling of the pressurized interface unit or by inducing a time delay between the compression phase and the expansion phase.

The concentric annular configurations proposed in Figs. 4A and 4B are simple, compact and efficient. As illustrated in Figs. 4A and 4B, the heat of the compressed air may be absorbed by say irrigation water or by cooling means such as a cooling coil and the like.

As demonstrated in Figs. 4A and 4B, a gas enrichment unit may be connected simultaneously with the gas line or the water line, thus, making the entire invigoration system environmentally friendly (Also may be included in Figs. 4A and 4B is a circulation stream to effectively achieve a required enrichment level as demonstrated below in Figs. 6 and 7).

It is to be noted, however, that according to the present invention, there is no need for forced cooling as in Figs. 4A-B, due to the discharge cooling during the recharging by the charging reservoir.

In accordance with some embodiments of the present invention, the proposed invigoration technology is best implemented by a multi-unit assembly, programmed to operate in predetermined sequences, to treat a fairly large space or various segments in parallel.

According to some embodiments of the present invention, the interface unit does not necessarily operate in a continuous mode, especially when multiple interface units participate to perform the invigoration processing, as shown below in Fig. 5. The multi-unit assembly of Fig. 5 represents a typical mode of operation that actually leaves enough time for the compressed air to dissipate the compression heat and thus return closer to the outdoor temperature. This is further detailed below.

Fig. 5 illustrates an assembly of multi-interface unit invigoration system 500 in parallel in accordance with some embodiments of the present invention.

As shown below, the arrangement in Fig. 5 aims to provide sources of multiple discharge or local continuous discharge (without the need for a time delay to cool the heat of compression). In accordance with some embodiments of the present invention, the assembly of multi-interface unit invigoration system 500 comprises at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 502. Compressor 502 is used to feed in sequence one by one, for example, three interface units, such as, for instance, a first interface unit 504A, a second interface unit 504B, and a third interface unit 504C, and a controller (not seen in the figure).

Each of the interface units may treat a specific, predefined, spot/volume. The three interface units, the first interface unit 504A, the second interface unit 504B, and the third interface unit 504C, may be programmed to operate in predefined time sequences and with various modes of discharge as described in Figs. 3A-3D.

All interface units 504A-C may be initially at pressure P_i (or each at a predetermined pressure). For instance, when the expansion phase in the first interface unit 504A comes to an end, the second interface unit 504B may go into its expansion phase, while recompression of the gas in the first interface unit 504A begins (and thus the interface unit 504A is refilled with compressed air). Similarly, when the second interface unit 504B completes its expansion phase, it is recompressed, while the third interface unit 504C goes into its expansion phase.

When all units are fully utilized, the multi-unit assembly is ready to repeat the discharge cycle again. The cycle of the three units actually represents a multiple cycle split in time and place in a continuous mode of operation.

In accordance with some embodiments of the present invention, by inducing a time delay between the compression phase and the expansion phase in each of the interface units 504A-C, the process in each of the interface units 504A-C is discontinuous. However, the entire process of the 504A-C interface units together is continuous.

In accordance with some embodiments of the present invention, the interface units 504A-C may be designed to operate at different zones and in different modes, namely: light or immediate ventilation, ventilation with cooling, aeration, with or without disinfection, etc.

Fig. 6 illustrates an assembly of multi-interface units invigoration system 600 for continuous discharge in accordance with some embodiments of the present invention.

As can be seen in the figure, the assembly of multi-interface units invigoration system 600 comprises at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 602 and multiple interface units, such as a first interface unit 604A, a second interface unit 604B unit, a third interface unit 604C, and an intermediate collection vessel 606.

In accordance with some embodiments of the present invention, each of the multiple interface units is drained into the intermediate collection vessel 606, wherefrom invigorating gas may be supplied. The advantage of having an intermediate collection reservoir 606 is to allow continuous operation.

The assembly of multi-interface units invigoration system 600 may further comprise an overall gas enrichment sub-unit (GEU) 608 where a stream of the gas enrichment sub-unit 608 may be directed into the intermediate collection vessel 606 and/or to the gas stream exiting the intermediate collection vessel 606 to enrich and cool the gas stream.

The gas enrichment subunit 608 may include a recirculation device to provide sufficient gas capacity. The circulation device ensures to achieve the required level of gas enrichment.

In accordance with some embodiments of the present invention, the assembly of the multi-interface units invigoration system 600 is a modification of the multi-

interface unit invigoration system 500, whereby the interface units, first interface unit 604A, second interface unit 604B, and third interface unit 604C are drained into an intermediate

collection vessel 606, wherefrom the invigorating air is supplied. Obviously, the intermediate collection vessel 606 can provide a continuous discharge to a single or multiple locations.

In accordance with some of the embodiments of the present invention, the gas in the interface units 504A-C in Fig. 5 and the gas in the interface units 604A-C in Fig. 6 may actually be simultaneously compressed each to its own pressure level according to a pre-set program as required.

In accordance with some embodiments of the present invention, a different indirect discharge scheme is illustrated in Fig. 7.

Fig. 7 illustrates an assembly of multi-interface units indirect charging invigoration system 700 for local invigoration in accordance with some embodiments of the present invention.

Seen in the figure, the assembly of multi-interface units indirect charging invigoration system 700 comprises at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 702, a pressurized vessel 704 and multiple interface units such as for instance a first interface unit 706A, a second interface unit 706B, and a third interface unit 706C.

As seen in the figure, the assembly of multi-interface units indirect charging invigoration system 700 may further comprise a central gas enrichment sub-unit (GEU) 708. The gas enrichment sub-unit 708 may replenish the discharged air.

The gas enrichment sub-unit 708 is aimed at renewing the exhaust air. The gas enrichment sub-unit 708 may be an input stream to the pressurized vessel 704 and/or an input stream to the first interface unit 706A, and/or the second interface unit 706B and/or the third interface unit 706C. In accordance with some embodiments of the present invention, the compression of the interface units, interface unit 706A, interface unit 706B and interface unit 706C, is carried out indirectly through pressurized vessel 704, which is maintained at higher pressure and is aimed at charging the interface units, interface unit 706A, interface unit 706B, and interface unit 706C.

In accordance with some of the embodiments of the present invention, the indirect charging of the interface unit 706A, and/or the interface unit 706B, and/or the interface unit 706C with a higher pressure gas exiting the pressure vessel 704 does not heat the interface unit 706A, the interface unit 706B, and the interface unit 706C, but on the contrary may have a cooling effect both when the gas pressure in the pressure vessel 704 decreases (a) while charging at least one of the interface unit 706A, the interface unit 706B, and the interface unit 706C and (b) while at least one of the interface unit 706A, the interface unit 706B and the interface unit 706C is

discharging. Furthermore, the heating of the pressure vessel 704 in its recompression phase is quite moderate, since the compressor 702 only needs to supply the missing gas in the pressure vessel 704.

According to certain embodiments of the present invention, since the pressure tank 704 is larger than each of the interface unit 706A, the interface unit 706B, and the interface unit 706C, the amount of gas required to fill the pressure tank 704 is relatively small, and the temperature increase due to the gas recharge is moderate, therefore, there is no need to cool the pressure vessel 704 during the recompression step.

In accordance with some embodiments of the present invention, in the multi-interface unit invigoration system seen in Figs. 5 and 7, the multiple interface units are arranged in parallel, and gas compression into each of the multiple interface units and/or gas expansion from each of the multiple interface units is either continuous or activated by at least one predefined time sequence.

Fig. 8 illustrates a comprehensive assembly for timewise and a spot wise invigoration 800 in accordance with some embodiments of the present invention.

Seen in the figure, the comprehensive assembly for timewise and a spot wise invigoration 800 may comprise at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 802, a pressurized vessel 804 and multiple interface units, a first interface unit 806A, a second interface unit 806B and a third interface unit 806C and a storage container 808 into which the multiple interface units are drained and wherefrom the invigorating air can be supplied continuously.

In accordance with some embodiments of the present invention, the compression of the interface units, interface unit 806A, interface unit 806B and interface unit 806C, may be carried out indirectly through pressurized vessel 804, which is maintained at higher pressure and is aimed at charging the interface units, interface unit 806A, interface unit 806B, and interface unit 806C.

In accordance with some embodiments of the present invention, the storage container 808 can provide a continuous discharge to a single or multiple locations.

The comprehensive assembly for timewise and a spot wise invigoration 800 can be programmed to operate with direct charging or indirect charging of each one of the interface units 806A-C.

As in the previous embodiments, various discharge modes may be integrated to yield the optimal invigoration in time and in place.

The comprehensive assembly for timewise and a spot wise invigoration 800 may further comprise a gas enrichment sub-unit (GEU) to replenish the discharged air. The gas enrichment sub-unit may be coupled with at least one of the first interface unit 806A, a second interface unit 806B and a third interface unit 806C and/or with the pressurized vessel 804 and with the storage vessel 808.

As can be seen below in Figs. 9A-B and 10A-B, the multiple interface units may have multiple volumes and may be arranged by volume, i.e., smallest to largest volume in order, or largest to smallest volume in order.

As can be seen in Figs 9A and 10A, small volume interface unit(s), medium volume interface unit(s), and large volume interface unit(s) may be arranged in a successive manner, wherein one of the small volume interface unit(s) may be a charging high pressure interface unit, and wherein an expansion phase may start from a high pressure level in the charging high pressure small interface unit and may continue successively to a lower pressure level in the large volume interface unit(s).

As can be seen in Figs 9B and 10B, large volume interface unit(s), medium volume interface unit(s), and small volume interface unit(s) may be arranged in a successive manner, wherein one of the large volume interface unit(s) is a charging high pressure interface unit, and wherein an expansion phase starts from a high pressure level in the large charging high pressure interface unit and continues successively to a lower pressure level in the small volume interface unit(s).

Fig. 9A illustrates a multi storage unit, low pressure discharge assembly 900 in accordance with some embodiments of the present invention.

Seen in the figure, the multi storage unit, low pressure discharge assembly 900 comprises at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 902 and multiple interface units arranged by size, for instance, a first small interface unit 904, a second medium interface unit 906, and a third large interface unit 908 set in a successive manner following each other.

In accordance with some embodiments of the present invention, the charging high pressure interface unit may be the first small interface unit 904.

In accordance with some embodiments of the present invention, the expansion phase may start from the high pressure level in the first small interface unit 904 and may continue successively to the lower pressure level in the third large interface unit 908. Each expansion stage may produce a cooling effect that occurs between successive stages, while charging the next stage.

Fig. 9B illustrates a multi storage unit, high pressure discharge assembly 950 in accordance with some embodiments of the present invention.

Seen in the figure, the multi storage unit, low pressure discharge assembly 950 comprises at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 952 and multiple interface units arranged by size, such as for instance, a first large interface unit 954, a second medium interface unit 956, and a third small interface unit 958 set in a successive manner following each other.

In accordance with some embodiments of the present invention, the charging high pressure interface unit may be the first large interface unit 954.

In accordance with some embodiments of the present invention, the expansion phase may start from the high-pressure level in the first large interface unit 954 and may continue successively to the lower pressure level in the third small interface unit 958. Again, each expansion stage produces a cooling effect, while charging the next stage.

The multi storage unit, high pressure discharge assembly 950 comprises multiple expansion stages of sequential volumes, such as three expansion stages of sequential volumes, set in successive manner following each other.

In accordance with some embodiments of the present invention, the charging high pressure interface unit may be the large volume interface unit, first large interface unit 954.

In accordance with some embodiments of the present invention, the expansion phase may start from the high pressure level in the first large interface unit 954 and may continue successively to the lower pressure level in the third small interface unit 958. Each expansion stage may produce a cooling effect, while charging the next stage.

The configurations illustrated in Figs. 9A and 9B are extensions of the configuration of Figs. 6 and 7. However, the successive expansion in multi-stage expansion process as in figures 9A and 9B, yield further intensive cooling.

The gas exiting the third large interface unit 908 in Fig. 9A may be a relatively low pressure gas, while the gas exiting the third small interface unit 958 may be a relatively high pressure gas. Thus, Since the pressure of the gas exiting from the third small interface unit 958 discharge interface unit may be significantly higher than the pressure of the gas exiting from the third large interface unit 908, the configuration in Fig. 9A may lead to a moderate cooling, whereas the configuration in Fig. 9B may result in an intensive cooling.

In accordance with some embodiments of the present invention, there may be several modes of operation to the multi storage unit, low pressure discharge assembly 900 of Fig. 9A and the multi storage unit, high pressure discharge assembly 950 of Fig. 9B:

A- The interface units may be charged successively each to a predetermined pressure level. The discharge may be triggered from the last interface unit as illustrated in figures 9A-B, i.e., from the third large interface unit 908 in Fig. 9A and from the third small interface unit 958 in Fig. 9B.

B- The discharge may actually be activated at each interface unit, simultaneously or sequentially, resulting in different levels of expansion due to the different pressure level at each interface unit. Thus, the multi storage unit, low pressure discharge assembly 900 of Fig. 9A, the multi storage unit, high pressure discharge assembly 950 of Fig. 9B, and the assemblies shown and described in Figs. 10A-B can be simultaneously programmed to provide various cooling levels.

C- The interface units of Figs. 9A-B and Figs. 10A-B (shown and described below), may operate continuously as the charging and discharging to/from the interface units may be continuous and/or in parallel.

In Figs. 10A-B, at least one small volume interface unit may be situated in at least one larger volume interface unit, and the at least one larger volume interface unit may be situated in at least one even larger volume interface unit to have a direct heat transfer, to cool each other while the compressed gas in each of the interface units undergoes an expansion phase.

Fig. 10A illustrates a multi-stage unit inner to exterior assembly 1000 in accordance with some embodiments of the present invention.

Seen in the figure, the multi storage unit, inner to exterior assembly 1000 may comprise at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 1002 and multiple pressurized interface units such as for instance a first small interface unit 1004, a second medium interface unit 1006, and a third large interface unit 1008.

In accordance with some embodiments of the present invention, the charging high pressure interface unit may be the first small interface unit 1004.

In accordance with some embodiments of the present invention, the expansion phase may start from the high pressure level in the first small interface unit 1004 and may continue successively to the lower pressure level in the third large interface unit 1008. Each expansion stage produces a cooling effect, while charging the next stage. More specifically, since the interface units are positioned inside one another - the first small interface unit 1004 may be inside the second medium interface unit 1006, and the second medium interface unit 1006 may be inside the third large interface unit 1008, there is a heat transfer among the interface units. For instance, when the compressed gas in the first small interface unit 1004 undergoes expansion, and thus,

cooling, the second medium interface unit 1006 is being cooled as a result of direct heat transfer the (since the first small interface unit 1004 is inside the second medium interface unit 1006). Fig. 10B illustrates a multi-stage unit exterior to inner assembly 1050 in accordance with some embodiments of the present invention.

Seen in the figure, the multi storage unit, inner to exterior assembly 1050 comprises at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 1052 and multiple pressurized interface units such as for instance a first large interface unit 1058, a second medium interface unit 1056, and a third small interface unit 1054.

In accordance with some embodiments of the present invention, the charging high pressure interface unit is the first large interface unit 1058.

In accordance with some embodiments of the present invention, the expansion phase may start from the high pressure level in the first large interface unit 1058 and may continue successively to the lower pressure level in the third low interface unit 1054. Each expansion stage produces a cooling effect, while charging the next stage.

More specifically, since the interface units are positioned inside one another - the first small interface unit 1054 is inside the second medium interface unit 1056, and the second medium interface unit 1056 is inside the third large interface unit 1058, there is a direct heat transfer among the interface units. For instance, when the compressed gas in the third large interface unit 1058 undergoes expansion, and thus, cooling, the second medium interface unit 1056 is being cooled as a result of direct heat transfer (since the first small interface unit 1054 is inside the second medium interface unit 1056 which is inside the third large interface unit 1058).

The multi-stage unit inner to exterior assembly 1000 and multi-stage unit exterior to inner assembly 1050 may further comprise a gas enrichment sub-unit (GEU) to replenish the discharged air.

In accordance with some embodiments of the present invention, the configuration in Fig. 10A represents moderate cooling, while the configuration in Fig. 10B may result in intensive cooling, since it is practical to create a higher pressure in the discharge of the first small interface unit 1004 than the third large interface unit 1058.

In accordance with some embodiments of the present invention, multi-stage unit inner to exterior assembly 1000 and multi-stage unit exterior to inner assembly 1050 are suitable for the design of compact portable units.

Since the interface units in Figs 10A and 10B are inside each other and may be in contact with each other, they cool each other while the gas in then undergoes an expansion stage.

Whereas Figs. 10A-B refer to concentric annular structures – concentric annular interface units, Figs. 10C-D, demonstrate additional unique features that can be achieved by non-concentric structures – non-concentric interface units.

Fig. 10C illustrates a multi-stage non-concentric inner to outer assembly 1080 in accordance with some embodiments of the present invention.

As seen in the figure, the multi-stage non-concentric inner to outer assembly 1080 comprises at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 1082 and multiple pressurized interface units such as for instance a first small interface unit 1084, a second medium interface unit 1086, and a third large interface unit 1088.

In accordance with some embodiments of the present invention, the charging high pressure interface unit may be the first small interface unit 1084 as seen in the figure.

Fig. 10D illustrates a multi-stage non-concentric outer to inner assembly 1090 in accordance with some embodiments of the present invention.

As seen in the figure, the non-concentric multi storage unit, outer to inner assembly 1090 may comprise at least one compressed air source such as a vessel (not seen in the figure) or at least one compressor such as compressor 1092 and multiple pressurized interface units such as for instance a first large interface unit 1098, a second medium interface unit 1096, and a third small interface unit 1094.

In accordance with some embodiments of the present invention, the charging high pressure interface unit may be the first large interface unit 1098 as seen in the figure.

Unlike the concentric annular structures multi storage unit of Figs. 10A-B, where the gas expansion in one interface unit lowers the temperature of the expanding gas discharged from said one interface unit, in the non-concentric multi storage unit, inner to exterior assemblies of Fig. 10C and in the non-concentric multi storage unit, exterior to inner assemblies of Fig. 10D, expansion and cooling occur in each of the interface unit due to the generation of local Venturi effect due to local variations in the path of the gas stream within the interface unit.

In accordance with some embodiments of the present invention, the local expansion in each interface unit may be determined by the eccentricity of the non-concentric structure.

Also, the reversal of the flow inside the interface unit and the local turbulence of the air flow induce the temperature reduction of the temperature drop (due to work produced by the gas).

In accordance with some embodiments of the present invention, the gas may be accelerated by entering through at least one narrow gap into the non-concentric interface unit, and then, may expand immediately upon exiting the non-concentric interface unit through at least one wide

gap. The at least one wide gap may be on the opposite peripheral side or bottom region of the concentric interface unit.

As mentioned, the reversal of the flow and the local turbulence cause an additional drop in temperature at the cost of the drop in internal energy. This is repeated in each interface unit.

In accordance with some embodiments of the present invention, the configurations of Figs. 9A-B and 10A-D may all be pre-programmed to operate in a continuous mode, providing gas streams such as fresh air streams at varying levels of cooling and cooling capabilities.

In accordance with some embodiments of the present invention, each of the multi-unit assemblies of Figs. 5-10, can be adapted and installed according to the specific case in question. For example, if a given commercial space or greenhouse is considered, the multi-interface unit assemblies can take advantage of the existing set of compressors aimed at driving forced ventilation from the outside into the interior space. However, it should be noted that each of the interface units in Figs. 3-10, can adopt a nearly isothermal compressor in order to alleviate the heat of compression. Isothermal compression is also significantly more energy efficient.

In each of the multi- interface unit assemblies proposed here, the compressors are used to drive the interface units and thus affect the local effective invigoration properties as desired, instead of vigorous forced ventilation throughout the space. The flow can be directed to the growers locally ideal spot-wise internal climate conditions, to the specific type of crops, the external conditions, the size of the greenhouse, etc.

In addition, each one of the multi-interface assemblies described above can be easily integrated with existing systems to provide both fresh and cooled refreshment. For example, a common central air conditioning system includes at the same time an auxiliary system for supplying fresh air, which usually works in series with the main air conditioning system, see Figures 11. The fresh air system draws air from the outside and exchanges heat with the air condition system to deal with the internal regulated temperature.

In accordance with some embodiments of the present invention, each of the multi-interface unit assemblies of Figs. 5-10 may be used to regulate indoor air quality.

In accordance with some embodiments of the present invention, in case the multiple interface units are arranged in a consecutive manner as in Figs, 6, 8, 9A-B and 10A-B, the compressed gas is transferable from each of the multiple interface units to a consecutive receiving interface unit, thus, gas expansion associated with cooling in each of the multiple interface units leading to gas compression associated with heating in the consecutive receiving interface unit.

In accordance with some embodiments of the present invention, the temperature in each of the multiple interface units is controlled by the mode of operation, either a continuous mode of

operation or a non-continuous mode of operation set by at least one predefined time sequence of the gas compression and the gas expansion in each of the multiple interface units.

In accordance with some embodiments of the present invention, in the non-continuous mode of operation, the gas expansion and the gas compression may take place interchangeably at predefined times in each of said multiple interface units.

It should be noted that in accordance with some embodiments of the present invention, any one of the above-described assemblies in Figs 1-10A-B may comprise a gas enrichment sub-unit (GEU) to replenish the discharged air.

Fig. 11 shows a multi-interface unit 1100 of the present invention for fresh air in conjunction with the main air conditioning system. As can be seen in the figure, the multi-interface unit of the present invention can be easily integrated with the fresh air system, thus it may be integrated into the conventional central air conditioning system, in order to efficiently energize the fresh air sub-system with high energy savings.

In accordance with some embodiments of the present invention, a multi-interface unit invigoration method comprising:

- providing the multi-interface unit invigoration system described above,
- arranging the multiple interface units either in parallel or in a consecutive manner,
- programming the multiple interface units to provide compressed gas either to a predefined spot/volume or to multiple spots/volumes,
- to insure effective and well-controlled cooling, maintaining the compressed gas at a predefined temperature, in each of the multiple interface units, and
- programming each of the multiple interface units to receive the compressed gas and to expand the compressed gas continuously or via at least one predefined time sequence to control the temperature of each of the multiple interface units.

In accordance with some embodiments of the present invention, connecting the multiple interface units in a consecutive manner, so that expansion associated with cooling in one interface unit leading to compression associated with heating in a consecutive interface unit.

In accordance with some embodiments of the present invention, wherein inducing a time delay between a compression phase and an expansion phase in each of the multiple interface units for controlling the temperature in each of the multiple consecutive interface units.

EXPERIMENTAL DATA

The multi-interface unit invigoration system of the present invention was designed and constructed to broadly illustrate the physical capabilities for simultaneous local cooling of

multiple components. Various practical processes have demonstrated long-term alternate discharge, continuous discharge, use of different discharge devices under wide operating conditions as detailed below.

The structure of the multi-interface unit invigoration system, the construction, and the experimental results are described as follows.

Fig. 12A is a flow diagram of the multi-interface unit invigoration system 1200 of the present invention and Fig. 12B shows the actual multi-interface unit invigoration used for conducting the experiments.

As seen in the figure, the multi-interface unit invigoration system comprises a pressurized reservoir 1202 and multiple interface units such as a first interface discharge unit 1204A and a second interface discharge unit 1204B.

The multi-interface unit invigoration system further comprises an air compressor 1206, air filter dryer 1208, a nozzle 1210, means for reducing the air pressure (i.e., 10 bar to 6 bar) 1212 and multiple valves.

The two interface discharge units 1204A-B are charged directly by a compressor or indirectly through a pressurized reservoir 1202, which has a larger volume and is maintained at a higher pressure. The pressurized reservoir 1202 charges the interface discharge units 1204A-B simultaneously or sequentially.

The indirect charging of the interface discharge units 1204A-B via a pressure reservoir 1202 not only moderates and restrains the heating of the interface discharge units 1204A-B, but may have a cooling effect when the pressurized gas of the pressurized reservoir is discharged into the discharge units 1204A-B, while charging the discharge units 1204A-B (i.e., illustrated below).

The multi-interface unit invigoration system 1200 consists of two discharge units which can be programmed to deliver gas to a number of predetermined points/volumes, alternately, continuously or by at least one predefined time sequence.

Obviously, the system may include more discharge units as illustrated in the embodiment of Fig. 7. The system may operate with one of the discharge units or simultaneously with all of the units, each in a different operational process.

Each of the multi-interface units is controlled to cool at least one selected component according to the desired degree of cooling. The desired gas expansion intensity, between successive stages, can be achieved by the discharge pressure and the discharge device. Thus, the gas temperature is controlled by the intensity of gas expansion in each of the aforementioned multi-interface units.

In order to ensure effective and well-controlled cooling, the gas is kept at a pre-cooled temperature, in each of the aforementioned multiple interface units, due to previous expansion.

Each of the multiple interface units is programmed to receive the compressed gas and expand the compressed gas continuously or in at least one predefined time sequence, whereby the multi-interface unit system cools multiple components at multiple temperatures simultaneously.

The multi-interface unit invigoration system 1200 is programmed to operate with direct compression or indirect charging of each of the interface discharge units 1204A-B, with a pre-cooling step or without any pre-cooling between successive discharges.

Fig. 13 illustrates the temperature drop of discharge unit 1204A at a discharge Pressure of 8 bar and pre-cooling.

The figure illustrates the temperature drop due to an instantaneous discharge, by an electric solenoid at a discharge pressure level of 8 bar, inside the discharge unit, right at the exit and away from the exit.

Obviously, the discharge may be triggered at any pressure level.

T2 refers to the temperature inside the discharge unit far from the exit, T4 refers to the temperature at the exit, while T6 refers to the temperature far from the exit (about 20 cm).

Fig. 14A is a graph of temperature drop versus pressure discharge. The figure illustrates temperature drop due to direct compression and discharge with discharge unit 1204A, with a precooling phase.

Fig. 14B is a graph of temperature drop versus discharge pressure. The figure illustrates a temperature drop due to direct compression and represents a comparison of discharge with or without Pre-Cooling discharge unit 1204A.

The results so far relate to direct compression of the discharge units. However, as detailed above, the charge reservoir is charged by direct compression to a higher pressure of 12 bar and is maintained at nearly 12 bar. According to the physical principles of the present invention, the compression of the charge reservoir is actually done gradually, since its function is actually to recharge the discharge unit, usually to a lower pressure, 2-8 bar.

Charging the discharge unit using a higher pressure and larger volume charge reservoir may moderate the rate of heating in the discharge unit and save energy compared to direct compression by a compressor.

Charging the discharge unit by a pressurized reservoir is denoted here as indirect charging.

Indeed, the heating rate with gradual compression of the charging reservoir is moderate as seen in Fig. 15A, while the charging process of the discharge units affects the cooling of the charging reservoir, Fig. 15B.

In view of the above, Fig. 16 refers to the heating rate of the discharge unit due to indirect charging by the charging reservoir, with or without a pre-cooling step. As seen in the figure, the heating rate due to indirect charging is indeed very moderate.

Fig. 17A shows the temperature drop for various pressure ranges with the precooling step.

Fig. 17B represents a comparison of the temperature drop with or without precooling phase, utilizing indirect charging.

As seen in the figure, precooling before discharge affects a more pronounced temperature drop in the discharge.

Fig. 18 refers to alternating discharge of the two discharge units 1204A-B. Both units are charged by the charging reservoir. The charging pressure in the charging reservoir is constantly maintained around 12 bar, while the discharge units are charged to pre-planned pressure level of 2, 4, 6, or 8 bar. Fig. 18 indicates a good match between the two discharge units.

Fig. 19 represents a fairly automatic continuous alternating discharge of the two units 1204A-B, while both units are charged intermittently by the charging reservoir to a given pressure, for instance 8 bar.

The results in Fig. 19 simulates a long-term operation of the two units at a constant discharge pressure of 8 bar, with good reproducibility of the cooling effects obtained with both units.

Fig. 20 illustrates a continuous process of simultaneous charging and discharging. As soon as the pressure in the discharge unit reaches a pre-programmed level, the discharge occurs simultaneously with the continuing charging process to ensure a continuous cooling effect. In Fig. 20, the discharge pressure is 8 bar, while the charging pressure is either 8 bar, 10, or 12 bar.

Fig. 21 represents continuous simultaneous charging and discharging as in Fig. 20, with the distinction that the valve between the charging reservoir and the discharging unit is shut down during the discharging process in order to avoid interference of the recharge process, as long as the discharge takes place.

As shown in Fig. 21, the activation of the charging pressure is at 12 bar, the pressure in the discharging unit reaches the predetermined desired level, say 8 bar, then the valve between the charging and discharging unit is closed first and the discharging process is triggered. It is clear that the cooling effect is higher as the connection between the charging reservoir and the discharging reservoir is withheld, as can be seen by comparing Figs. 20 and 21.

Overall, the embodiments presented above with the experimental results prove that it is possible to plan the temperature management of several components simultaneously at different levels as needed, taking advantage of energy savings in indirect charging, associated with moderate heating during the recharging stages.

CLAIMS:

1. A multi-interface unit invigoration system for providing invigoration and/or cooling via continuous or noncontinuous controlled modes of operation, the system comprising:
either concentric or non-concentric multiple interface units, said multiple interface units are programed to provide gas either to a predefined spot/volume or to multiple spots/volumes, either continuously or by at least one predefined time sequence,
at least one compressed gas source for providing compressed gas to at least one of said multiple interface units,
a controller,
wherein to insure effective and well-controlled cooling, the compressed gas is maintained at a predefined temperature, in each of said multiple interface units,
wherein each of said multiple interface units is programmed to receive said compressed gas and to expand said compressed gas continuously or via at least one predefined time sequence to control the temperature of each of said multiple interface units,
whereby the multi-interface unit invigoration system providing invigoration and/or cooling with either continuous or noncontinuous controlled modes of operation.
2. The multi-interface unit invigoration system of claim 1, wherein said multiple interface units are arranged either in parallel or in a consecutive manner.
3. The multi-interface unit invigoration system of claim 1, wherein the compressed gas is selected from air, Nitrogen, Carbon dioxide, Ozone (O₃), and Oxygen (O₂).
4. The multi-interface unit invigoration system of claim 2, wherein in case said multiple interface units are arranged in a consecutive manner, the compressed gas is transferable from each of said multiple interface units to a consecutive receiving interface unit, thus, gas expansion associated with cooling in each of said multiple interface units leading to gas compression associated with heating in said consecutive receiving interface unit.

5. The multi-interface unit invigoration system of claim 2, wherein in case said multiple interface units are arranged in parallel, gas compression into each of said multiple interface units and/or gas expansion from each of said multiple interface units is either continuous or activated by at least one predefined time sequence.
6. The multi-interface unit invigoration system of claim 1, wherein the temperature of the gas being discharged from each of said multiple interface units is controlled by a mode of operation, either a continuous mode of operation or a non-continuous mode of operation set by at least one predefined time sequence of said gas compression and said gas expansion in each of said multiple interface units.
7. The multi-interface unit invigoration system of claim 5, wherein in said non-continuous mode of operation, the gas expansion and the gas compression take place interchangeably at predefined times in each of said multiple interface units.
8. The multi-interface unit invigoration system of claim 1, wherein the at least one compressed gas source is a compressor.
9. The multi-interface unit invigoration system of claim 1, wherein the at least one compressed gas source is a vessel containing compressed gas.
10. The multi-interface unit invigoration system of claim 1, further comprising at least one pressure vessel.
11. The multi-interface unit invigoration system of claim 1, wherein each of the multiple interface units comprises a discharge device.
12. The multi-interface unit invigoration system of claim 10, wherein the discharge device is selected from a moderate controlled quasi-reversible discharge device, a nozzle discharge device, an instantaneous prompt solenoid discharge device, and a turbine.
13. The multi-interface unit invigoration system of claim 11, wherein the instantaneous discharge device is a solenoid valve.

14. The multi-interface unit invigoration system of claim 1 further comprising a gas enrichment sub-unit (GEU), said gas enrichment sub-unit (GEU) providing an enriching gas stream connected to at least one gas stream discharged from at least one of said multiple interface units to enrich said at least one gas stream being discharged from the at least one of said multiple interface units.
15. The multi-interface unit invigoration system of any one of claims 1 and 13, further comprising a purifying gas stream discharge unit for providing a purifying gas stream.
16. The multi-interface unit invigoration system of claim 14, wherein the purifying gas stream is connected to the enriching gas stream provided to at least one of said multiple interface units to purify said gas stream.
17. The multi-interface unit invigoration system of claim 15, wherein the enriching gas and/or the purifying gas is selected from air, Nitrogen, Carbon dioxide, Ozone (O₃), and Oxygen (O₂).
18. The multi-interface unit invigoration system of claim 3, wherein when an expansion phase in one interface unit comes to an end, a consecutive interface unit goes into its expansion phase, while recompression begins in the one interface unit, and when the consecutive interface unit completes its expansion phase, it is recompressed, while the following interface unit goes into its expansion phase.
19. The multi-interface unit invigoration system of claim 1, wherein each one of the interface units operates in a mode selected from light or immediate ventilation mode, ventilation with cooling mode, and aeration mode with or without disinfection.
20. The multi-interface unit invigoration system of claim 1, further comprising an intermediate collection vessel, wherein each of the multiple interface units is drained into said intermediate collection vessel, wherefrom invigorating gas is supplied.
21. The multi-interface unit invigoration system of claim 1, further comprising a pressurized vessel for indirect charging of the multiple interface units, said pressurized vessel is charged with compressed gas via said at least one compressed gas source and

is maintained at high pressure, said pressurized vessel is connected to each of the multiple interface units for charging each of the interface units with compressed gas either continuously or via at least one pre-defined time sequence.

22. The multi-interface unit invigoration system of claim 1, wherein said multiple interface units have multiple volumes.
23. The multi-interface unit invigoration system of claim 21, wherein said multiple interface units having multiple volumes are arranged by volume.
24. The multi-interface unit invigoration system of claim 22, wherein small volume interface unit(s), medium volume interface unit(s), and large volume interface unit(s) are arranged in a successive manner, wherein one of the small volume interface unit(s) is a charging high pressure interface unit, and wherein an expansion phase starts from a high pressure level in the charging high pressure small interface unit and continues successively to a lower pressure level in the large volume interface unit(s).
25. The multi-interface unit invigoration system of claim 22, wherein large volume interface unit(s), medium volume interface unit(s), and small volume interface unit(s) are arranged in a successive manner, wherein one of the large volume interface unit(s) is a charging high pressure interface unit, and wherein an expansion phase starts from a high pressure level in the large charging high pressure interface unit and continues successively to a lower pressure level in the small volume interface unit(s).
26. The multi-interface unit invigoration system of any one of claims 21-24, wherein said small volume interface unit(s) is situated in said medium volume interface unit(s), and said medium volume interface(s) unit is situated in said large volume interface unit(s) to have a direct heat transfer, to cool each other while the compressed gas in each of said interface units undergoes an expansion phase.
27. The multi-interface unit invigoration system of claim 26, wherein said multi-interface unit invigoration system is a non-concentric multi storage unit, where expansion and cooling occur in each of the interface units due to generation of

local Venturi effect due to local variations in the path of the gas stream within each of the interface unit.

28. The multi-interface unit invigoration system of claim 27, wherein a local expansion in each of said interface units is determined by the eccentricity of the non-concentric interface unit.
29. The multi-interface unit invigoration system of claim 28, wherein a flow reversal in each of the interface units, and a local turbulence of the gas flow, induce temperature reduction.
30. The multi-interface unit invigoration system of claim 29, wherein the gas is accelerated by entering through at least one narrow gap into the non-concentric interface unit, and then, the gas expanding immediately upon exiting the non-concentric interface unit through at least one wide gap.
31. The multi-interface unit invigoration system of claim 29, wherein a gas flow reversal and local turbulence causing a temperature drop.
32. The multi-interface unit invigoration system of any one of claims 1-31, wherein the multi-interface unit invigoration system is pre-programmed to operate in a continuous mode, providing gas streams at various levels of cooling and cooling capabilities.
33. A multi-interface unit invigoration method comprising:
 - providing the multi-interface unit invigoration system of claims 1-32;
 - arranging said concentric or non-concentric multiple interface units,
 - programming said concentric or non-concentric multiple interface units to provide compressed gas either to a predefined spot/volume or to multiple spots/volumes,
 - to insure effective and well-controlled cooling, maintaining the compressed gas at a predefined temperature, in each of said multiple concentric or non-concentric interface units;
 - programming each of said concentric or non-concentric multiple interface units to receive said compressed gas and to expand said compressed gas continuously or

via at least one predefined time sequence to control the temperature of each of said concentric or non-concentric multiple interface units.

34. The multi-interface unit invigoration method of claim 33, wherein connecting said concentric or non-concentric multiple interface units in a consecutive manner, so that expansion associated with cooling in one concentric or non-concentric interface unit leading to compression associated with heating in a consecutive concentric or non-concentric interface unit.
35. The multi-interface unit invigoration method of claim 33, wherein inducing a time delay between a compression phase and an expansion phase in each of said concentric or non-concentric multiple interface units for controlling the temperature in each of said multiple consecutive concentric or non-concentric interface units.