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(54) **Controlling humidity in zones during a drying process**

(57) A method of controlling humidity in each of a plurality of zones of an enclosed space during a drying process includes, in each zone, drawing air from the zone to create an air stream (9) through a heating element (15) and discharging the air stream into the zone; sensing the relative humidity of the air in a sensing location in the

zone; in response to the relative humidity sensed at the sensing location, operating the heating element (15) to raise a temperature of the air stream (9) as required to reduce the relative humidity of the air in the zone to a desired relative humidity. The method reduces over-drying and increases the efficiency of the drying process.

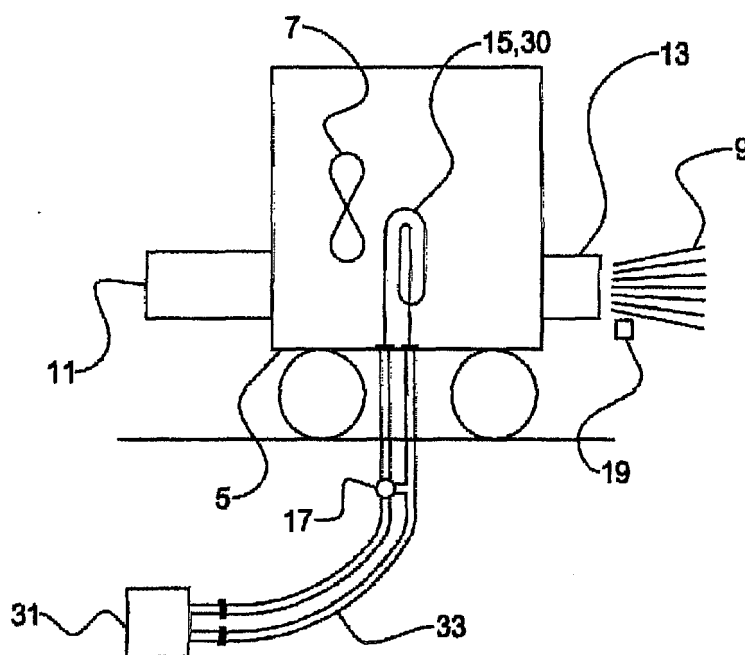


FIG 1

Description

[0001] This invention is in the field of removing moisture from buildings and like enclosed spaces, and in particular methods for controlling such removal to maximize efficiency.

BACKGROUND

[0002] It is well known that excessive moisture in buildings causes considerable problems. Drywall and flooring absorb moisture and are readily damaged if the excessive moisture condition persists for any length of time. Interior elements such as insulation, studs, and joists can eventually be affected as well. Furthermore, mold begins to form on the damp building materials, and can remain in the structure even after it has dried, causing breathing problems for persons occupying the building.

[0003] At the extreme, such excessive moisture conditions are exemplified by a flooded building. United States Patent Number 6,457,258 to Cressy et al., "Drying Assembly and Method of Drying for a Flooded Enclosed Space", discloses an apparatus for drying flooded buildings that overcomes problems in the prior art. Such prior art is said to require stripping wall and floor coverings and using portable dryers to circulate air to dry out the exposed floor boards, joists and studs. The methods were slow and allowed mold to form on the interior framing, which could then go unnoticed and be covered up and then later present a health hazard to occupants.

[0004] The solution proposed by Cressy is to introduce very hot and dry air into the building, indicated as being at 125 °F and 5% relative humidity, in order to dry the building very quickly to prevent mold growth and allow an early return to occupants. In the apparatus of Cressy et al., outside air is heated by a furnace and the heated air is blown into the building where it picks up moisture and then is exhausted back outside. In Cressy heat from the warmer exhaust air is transferred to the cooler outside air prior to heating by the furnace, thereby increasing the efficiency of the system.

[0005] United States Patent Number 6,647,639 to Storrer, "Moisture Removal System", addresses the problem of extracting water promptly to prevent the formation of rot, mold, rust and the like in flooded buildings. Storrer reveals the prior art as including passive drying through opening windows, etc. and active drying using forced air (heated or not) to expedite evaporation. Storrer discloses using a blower to blow (or draw) dry air through a hose and manifolds that can be directed at a particular area that it is desired to dry.

[0006] In a similar vein, United States Patent Number 5,960,556 to Jansen, "Method for Drying Sheathing in Structures", is directed to drying walls with warm, low humidity air.

[0007] Prior art systems for drying flooded buildings also include dessicant dehumidifiers that use a desiccant material with a high affinity to water to absorb water from

the air, and refrigerant dehumidifiers that condense water out of the air by cooling it. In both of these systems, the water must be disposed of in some manner. The water absorbed by the dessicant material is removed by subsequently drying the material. The water condensed by the refrigerant system is collected in a reservoir that must be emptied from time to time or piped to a disposal area. Care must be taken that the collected water be removed so that mold does not form therein and disperse within the building.

[0008] While flooded buildings demonstrate an extreme situation, excessive moisture also causes problems in other situations as well. During construction wet conditions are often present in buildings. Long periods of rain during construction, burst pipes, wet building materials (such as concrete), and like conditions can contribute to humid conditions where excessive moisture can be absorbed by joists and studs. These moist members are often covered up by flooring and drywall such that drying is prevented, and rot, mold, and the like can form.

[0009] In cold climates it is also common to use construction heaters to warm buildings during construction. Such heaters that use combustion inside the building also cause a significant increase in the humidity of the air inside the building, contributing to excessive moisture inside walls and floors and the problems associated therewith.

[0010] The opposite condition of excessively dry air in a building can cause problems as well. Excessively dry air can draw moisture out of wood causing warping and splitting of floors and millwork.

[0011] In addition to buildings, other analogous enclosed spaces also can become wet and require drying. For example the interior holds of ships are subject to considerable corrosion from water in the bottom of the ship, and in the atmosphere within the hold. Periodically the hold must be repainted with a corrosion inhibitor, but the surfaces of the hold interior must be dry. Given the location deep within a ship, it is difficult to dry these holds. Conventionally such drying is accomplished by condensing the water in the air of the hold with refrigeration dehumidifiers after any standing water has been pumped out. The condensation process is time consuming and requires significant energy.

SUMMARY OF THE INVENTION

[0012] It is an object of the present invention to provide a method and apparatus for controlling the condition of air in enclosed spaces that overcomes problems in the prior art

[0013] The present invention provides, in a first embodiment, a method of controlling humidity in each of a plurality of zones of an enclosed space during a drying process. The method comprises in each zone, drawing air from the zone to create an air stream through a heating element and discharging the air stream into the zone; sensing the relative humidity of the air in a sensing loca-

tion in the zone; in response to the relative humidity sensed at the sensing location, operating the heating element to raise a temperature of the air stream as required to reduce the relative humidity of the air in the zone to a desired relative humidity.

[0014] The present invention provides, in a second embodiment, a method of drying an enclosed space. The method comprises providing a plurality of portable heat exchanger units, each portable heat exchanger unit comprising: a fan operative to create an air stream by drawing air from an intake and discharging the air through an outlet; a fluid coil located in the air stream; and a heat controller operative to adjust a flow of fluid through the fluid coil; positioning at least one portable heat exchanger unit as an outside air unit with the intake thereof oriented to draw air from outside the enclosed space and with the outlet thereof oriented to discharge the air stream thereof into the enclosed space; positioning a plurality of portable heat exchanger units as inside air units at spaced apart unit locations inside the enclosed space and orienting the intakes and outlets of each inside air unit to draw air from the enclosed space adjacent to the inside air unit and to discharge the air stream into the enclosed space adjacent to the inside air unit; connecting the fluid coils of each portable heat exchanger unit to a fluid heater and circulating heated fluid from the fluid heater through the fluid coils and operating the fans; sensing the relative humidity of the air stream created by each inside air unit; operating the heat controller of each inside air unit to raise a temperature of the corresponding air stream as required to reduce the relative humidity of the air stream to a desired relative humidity; and allowing an amount of air substantially equal to the amount of air drawn from outside the enclosed space to exhaust from the enclosed space.

[0015] Raising the temp of air 10 °C will reduce the relative humidity of the air by about 50%. By sensing the relative humidity of the air at a sensing location, conveniently at the air stream outlet a heat controller can be operated to supply heat at the proper rate to achieve a desired relative humidity in the air stream, and thus in the zone.

[0016] The relative humidity of the air is an indicator of how much water the air is holding, and thus how much more water it can hold. For example, in a closed room with standing water on the floor, the relative humidity would approach 100% (i.e. the air would become saturated with water) and so no more water would evaporate off the floor. Raising the air temp 10°C will reduce the relative humidity by 50%, resulting in a humidity gradient between the water and the air, and thus more water will evaporate off the floor and the relative humidity will again rise to 100%, provided no air moves in or out of the room. By bringing in a dryer air stream and thereby pushing the wet air out of the room through an exhaust, the water is literally carried out of the room by the exhaust air with the result that all the water will eventually evaporate and be carried out of the room.

[0017] On a wet day for example if the outside air has a relative humidity of 100%, raising the temperature of the outside air by 20 °C will reduce the relative humidity of the air stream to 25%. A relative humidity of 25% would be generally accepted to be desirable for a construction site, being neither too moist and thus promoting mold growth, nor too dry such that sensitive materials such as flooring and millwork would be adversely affected.

[0018] The amount of heat required to achieve the desired temperature rise will depend on the volume of air drawn into the air stream, which could be varied by increasing or decreasing the fan speed. In any event, the relative humidity can be sensed at the air outlet, and the amount of heat supplied then varied to achieve the desired relative humidity of the outside air stream at the output. Alternatively, the humidity and temperature could be sensed at the intake, and the temperature sensed at the outlet. The required adjustment in the amount of heat supplied could be calculated, given the relative humidity of the outside air being drawn in, by determining the temperature rise required to achieve the desired relative humidity of the air stream at the outlet.

[0019] Depending on the volume of the air stream and the size of the enclosed space, the relative humidity of the air inside the enclosed space will be reduced over some period of time as the dryer air stream pushes wetter air from inside the enclosed space out through open windows, doors, exhaust vents, or the like. The relative humidity of the inside air could also be sensed directly to control the temperature rise supplied by the heat source. Care should be taken however, since using such a direct control in a relatively large enclosed space could result initially in over drying of the air stream that could adversely affect materials near the outlet of the air stream.

[0020] Larger spaces present particular problems for drying by flushing dry air through the space and exhausting wetter air through a vent. In a larger space there is typically some distance between the location of the dry warm incoming air and the exhaust location. As the dry warm air moves through the space it absorbs moisture and the relative humidity of the air increases and reduces its ability to absorb further moisture. Further, as the air absorbs water, the phase change from liquid water to gaseous water vapor absorbs heat, reducing the temperature of the air and further increasing the relative humidity. Thus those areas near the wet air exhaust will experience less drying than areas near the dry air input.

[0021] Often buildings being dried are not well sealed, such that a considerable amount of air leaves the building through seams in the walls, or like leaks rather than through the vent. In areas near where such leakage is significant, over-drying can occur as the flow of air through the area is increased compared to other areas of the building.

[0022] Larger spaces also typically include areas or zones that are separated for example by walls into rooms, by shelves of stored goods such as in warehouses, by floors in multi-story buildings, and other like obstructions

to airflow through the space. Such obstructions create uneven air circulation and result in uneven humidity in the space, and thus uneven drying. The various zones of a larger space typically include areas that are wetter for one reason or another. During construction for example, certain procedures may be taking place in one zone that create significantly higher humidity than in others, such as crack filling drywall with drywall mud. Similarly where a building has been flooded, certain parts of the building will typically be wetter than others.

[0023] In order to provide more efficient and even drying, and to reduce the possibility of over-drying, the method of the present invention provides a plurality of portable heat exchanger units comprising a fan drawing air from an intake through a heating element and then out through an air output. The heating elements could be electrically powered, however a typical application will usually comprise a fluid coil connected to a fluid heater by conduits such that heated fluid circulates through the fluid coil. A heat controller on the unit is operative to increase or decrease the flow of heated fluid through the coil, and thus control the temperature rise between the air at the intake and that at the output.

[0024] Outside air heat exchanger units are configured to draw in outside air and direct a stream of warmed outside air with reduced relative humidity into the space to be dried. A further number of inside air heat exchanger units are distributed inside throughout the space to be dried. Each inside unit includes a humidity sensor connected to the heat controller to control the amount of heat added to the air drawn through the unit, and thus control the temperature rise of the air and the relative humidity thereof. The inside air heat exchanger units are set to create an air stream at the air output with a desired relative humidity level, typically 25 - 30% to provide effective drying without over-drying. The heat controller is operative to add sufficient heat to the air drawn in the intake thereof to reduce the relative humidity of the air stream at the air output to the desired level.

[0025] The inside air heat exchanger units are spaced generally evenly throughout the space to be dried. Due consideration may be given to any particular circumstances of the space being dried, such as larger or smaller rooms, wetter and drier areas, and like considerations but generally the object is to have portable heat exchanger units distributed throughout the space such that each draws in air from around its location and discharges the air stream back into the location.

[0026] The inside air heat exchanger units thus operate to bring the relative humidity of the air in the zones in which they are located to the desired level. As a particular zone dries, the relative humidity of the air in the zone will decrease and the amount of heat needed to bring the air stream at the output of that unit to the desired relative humidity will decrease. When the relative humidity in the zone reaches the desired level, the heat controller will stop the flow of heated fluid to that unit.

[0027] The fans in the heat exchanger units will cause

air to move throughout the building, such that air from one zone intermingles with air from another but the system operates such that the air in any one zone or area is brought down to the desired level, but no lower. At that time the fan will simply circulate the air until the relative humidity of the air in the zone rises again due to movement into the zone of wetter air from another zone. At that time the humidity sensor will sense that the relative humidity has risen, and call for heat to again reduce the relative humidity of the air stream to the desired level.

[0028] Thus the method of the present invention substantially prevents over-drying in one area or zone of a space being dried. In addition to damaging sensitive materials, over-drying wastes energy by expending heat energy to reduce the relative humidity of an area below what is desired or required for drying. The method of the present invention reduces energy costs by distributing heat only to those zones where it is required to reduce the relative humidity to the desired area.

DESCRIPTION OF THE DRAWINGS

[0029] While the invention is claimed in the concluding portions hereof, preferred embodiments are provided in the accompanying detailed description which may be best understood in conjunction with the accompanying diagrams where like parts in each of the several diagrams are labeled with like numbers, and where:

- Fig. 1 is a schematic side view of a portable heat exchanger unit for use in the method of the invention, wherein the heating element thereof is a fluid coil;
- Fig. 2 is a schematic side view of an alternate portable heat exchanger unit for use in the method of the invention, wherein the heating element thereof is an electric element;
- Fig. 3 is a schematic plan view of an enclosed space, such as a building interior or ship's hold, with portable heat exchanger units configured to practice a method of the invention;
- Fig. 4 is schematic plan view of a fluid heater and conduits connecting the fluid heater to the portable heat exchanger units of Fig. 3;
- Fig. 5 is a schematic plan view of an alternate enclosed space with portable heat exchanger units configured to practice a method of the invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0030] Figs. 1 and 2 schematically illustrate portable heat exchanger units 5, 105 each comprising a fan 7

operative to create an air stream 9 by drawing air from an intake 11 and discharging the air through an outlet 13. A heating element 15 is located in the air stream 9 and a heating source is connectable to the heat exchanger unit 5 to supply heat energy to the heating element 15 in response to directions from a heat controller 17. The heat exchanger unit 5 comprises a humidity sensor 19 placed at a sensing location where it is operative to sense the relative humidity of the air stream 9 and send a humidity signal to the heat controller 17. The heat controller 17 is operative to receive the humidity signal and change the amount of heat energy supplied to the heating element 15 in response to the humidity signal. Portability is provided by wheels or the like as illustrated.

[0031] In the embodiment of Fig. 1, the heating element 15 comprises a fluid coil 30 and the heating source is a fluid heater 31 connectable to the fluid coil 30 by conduits 33 such that heated fluid flows from the fluid heater 31 through the fluid coil 30 and back to the fluid heater 31. The fluid heater 31 is conveniently a water heater or boiler system set up at a central and connectable to a plurality of portable heat exchanger units 5. The flow of heated fluid through the coil 30 is controlled by a heat controller 17 which is operative to direct fluid from the fluid heater 31 either through the coil 30 or back to the fluid heater 31.

[0032] Fig. 2 illustrates an alternate embodiment of a heat exchanger unit 105 wherein the heating element 15 comprises an electric heating element 21 and the heating source is an electrical power outlet connectable to the electric element by a power cord in a conventional manner. The illustrated portable heat exchanger unit 105 also includes a fan controller 8 operative to change the speed of the fan 7 to vary the volume of air in the air stream 9. The fan controller can be manually controlled, or connected to receive the humidity signal, temperature signals or the like and programmed to vary the fan speed in response to information received. Thus both the volume and relative humidity of the air stream 9 can be varied in response to the humidity signal.

[0033] Raising the temp of air 10 °C will reduce the relative humidity of the air by about 50%. By sensing the relative humidity of the air stream 9 the heat controller 17 can be operated to supply heat at the proper rate to achieve the desired relative humidity in the air stream 9. Alternatively, temperature sensors could be provided and the humidity and temperature of the air coming into the unit 5 could be sensed at the intake 11, and the temperature of the air stream 9 sensed at the outlet 13. The required adjustment in the amount of heat supplied could be calculated, given the relative humidity of the air being drawn in, by determining the temperature rise required to achieve the desired relative humidity of the air stream 9 at the outlet.

[0034] Figs. 3 and 5 schematically illustrate a plurality of portable heat exchanger units 5 set up in enclosures 40 and 41, each enclosing an interior space that requires drying, in configurations to practice the method of the

invention for drying an enclosed space. The enclosures 40, 41 may be buildings that were flooded from rising waters outside the building or by a water leak inside the building. Such buildings may also require drying due to construction activities being carried on inside the building, such as plastering, pouring concrete or like activities that generate undesirable elevated moisture levels in the building. Similarly the enclosures 40, 41 could be the hold of a ship which is often divided into various compartments, or could be a large empty space.

[0035] Heated fluid flows to the portable heat exchanger units 5 through conduits 33 from a central fluid heater 31. The portable heat exchanger units 5 are connected in parallel with the supply conduits 33 as schematically illustrated in Fig. 4 and heat controllers 17 control the amount of heated fluid flowing through the fluid coil of each unit 5. The fluid heater 31 is typically set to provide heated fluid at the supply port 35 thereof at a pre-determined supply temperature. The heated fluid circulates through the coils of the portable heat exchanger units 5 and the heated fluid returns to the return port 37 of the fluid heater 31 at a reduced return temperature, is heated by the fluid heater to the supply temperature, and is pumped out the supply port to circulate again.

[0036] When using such a system with heat exchanger units 5 to dry a ship's hold, it will often be most convenient to position the fluid heater 31 on the ship's deck or other convenient location, and provide main conduits 33 carrying heated fluid to the drying location which may be deep within the ship, and connect same to the fluid coils 30 of the heat exchanger units 5 by smaller secondary conduits 33.

[0037] In order to provide drying of the enclosure interior, it is necessary to draw in outside air from outside the enclosure and allow an amount of air substantially equal to the amount of air drawn from outside to exhaust from the enclosure interior through a vent 42. Commonly, the outside air will have a relative humidity level that is above a level that will provide effective drying, and so it is necessary to reduce the relative humidity of the air drawn into the building to a level of about 25% - 30%. Air at these relative humidity levels provides a significant relative humidity difference between the air stream and liquid water in wet plastered walls, flooded areas, and the like, such that effective drying can be accomplished and yet over-drying is prevented. The drier the air the greater the moisture gradient between water and the air, and the faster the air will absorb moisture.

[0038] When using the present method to dry a ship's hold, it may be necessary to provide ducting to supply the outside air to the hold, and to provide an exhaust route to conduct exhaust air out of the hold.

[0039] In order to reduce the relative humidity of the air drawn into the enclosure, portable heat exchanger units 5 are positioned as outside air units 5A with the intakes 11 A thereof oriented to draw air from outside the enclosure 40 and with the outlets 13A thereof oriented to discharge the air streams 9A thereof into the enclosure

interior.

[0040] Drying can be accomplished by simply drawing in the outside air and discharging it into the enclosure interior at one or more locations as an air stream with the desired relative humidity, and then exhausting the air from the enclosure interior at another location such that the dry air streams 9A move through the enclosure absorbing moisture and then move out the exhaust as a wetter air stream.

[0041] As the dry air streams 9A move through the enclosure interior toward the vent 41, they absorb moisture which raises the relative humidity thereof and reduces the moisture gradient between the air in the enclosure interior and water in the enclosure, and thus reduces the ability of the air to dry the enclosure by absorbing water. When water is absorbed by the air it changes phase from a liquid to gaseous water vapor, a process which absorbs heat, and thus the air also cools as it moves through the enclosure interior and absorbs water. Since the relative humidity of air rises when the temperature cools, the drying effectiveness of the air stream is reduced by the cooling effect as well as the fact that the relative humidity is rising because the air is absorbing water from the enclosure interior. In such a system then the relative humidity of the exhaust air leaving the vent 42 has a higher relative humidity and lower temperature than the incoming air stream 9A.

[0042] The drying effect in such a system is thus uneven since air nearer the intake has a lower relative humidity than air near the vent 42. This uneven drying is exacerbated in an enclosure interior such as that illustrated in Fig. 3 that is divided into various rooms, and results in over-drying in some areas or zones of an enclosure interior, and increased drying times in other zones. Similar obstructions to air flow are presented by goods stacked in a warehouse, for example and like situations. While air circulation can be improved by providing a fan or like means to circulate air into and out of the rooms, air circulation is reduced in the individual rooms, in particular those rooms that do not include a vent.

[0043] The present invention therefore provides a plurality of portable heat exchanger units 5 positioned as inside air units 5B at spaced apart unit locations inside the enclosure interior. The intake 11 of each inside air unit draws air from the enclosure interior adjacent to the inside air unit and discharges an inside air stream 9B through the outlet 13 into the enclosure interior adjacent to the inside air unit. A humidity sensor on each unit 5B senses the relative humidity of the air stream 9B and sends a signal to the heat controller of the unit such that the flow of heated fluid through the coil is sufficient to reduce the relative humidity of the inside air stream 9B to reduce the relative humidity of the air stream to a desired relative humidity, typically 25% - 30%.

[0044] Thus each inside air unit 5B controls the relative humidity of the air in a zone comprising the immediate vicinity of the unit. In the configuration of Fig. 3, zones are fairly well defined by the rooms or compartments into

which the enclosure interior is divided. Two inside air units 5B are positioned in the larger room 44, and to dry a smaller room 46 one of the inside air units 5B is oriented to direct its air stream 9B into the room 46 through the bottom of a door forcing air in the room out through the top of the door.

[0045] In operation, the fans are operated and heated fluid is circulated from the fluid heater 31 through the coil of each portable heat exchanger unit 5. The outside air units 5A reduce the relative humidity of the outside air to the desired level by heating the air stream, and direct the outside air stream 9A into the enclosure interior. Each inside air unit 5B operates to reduce the relative humidity of the inside air streams 9B. The inside air will circulate from one zone to another, however at each inside air unit 5B, there will be created an inside air stream 9B with the desired relative humidity. When the relative humidity of the air being drawn into one of the inside air units 5B decreases, less heat will be required to reduce the relative humidity of the air stream 9B to the desired level and the heat controller will reduce the flow of heated fluid to the coil of the unit. Since less heat is being drawn from the circulating heated fluid, the return temperature of the heated fluid will increase, and the heat required to be generated by the fluid heater to heat the return fluid to the supply temperature will be reduced.

[0046] For example, in Fig. 3 one room may dry faster than another such that the relative humidity of the air in the room reaches the desired level, and the air entering the intake 11 of the inside air unit will not require any heating to maintain the air stream 9B at the desired level. The heat controller will cut off all flow of heated fluid through the coil. The fan however will continue to operate, and air will circulate and some of the air from the room, at the desired relative humidity level, will move out of the room and other air from the enclosure interior, at a relative humidity level above the desired level, will move into the room, raising the relative humidity level such that the air drawn in by the unit 5B, and also the air stream 9B, will have a relative humidity above the desired level. As the relative humidity of the air stream 9B increases, the heat controller will direct heated fluid through the coil to again reduce the relative humidity of the air stream 9B to the desired level.

[0047] Thus at substantially all times in every zone of the enclosure, interior air at the desired relative humidity level is discharged from each inside air unit 5B. When one zone is dry such that the air there is at the desired level of relative humidity, heat to the inside air unit in that zone is cut off. Thus as each different zone of the enclosure interior dries, the relative humidity decreases in each zone and progressively less heat is required from the fluid heater. Circulating air moves from one zone to the next, but by sensing the relative humidity of each air stream 9B the system automatically compensates and works toward reducing the relative humidity of the entire interior of the enclosure to the desired relative humidity. Once that is achieved, drying is generally complete.

[0048] During the drying process using the method of the invention, as air moves from the outlets of the outside air units 5A through the wet enclosure interior to the vent 42 it will absorb moisture, however the relative humidity of the air throughout the enclosure interior is maintained at substantially the same desired level by the inside air units 5A. The exhaust air stream 9C leaving through the vent 42 thus has substantially the same relative humidity as the incoming air streams 9A, but it carries substantially more water because the temperature is higher. Each inside air unit raises the temperature of the air to reduce the relative humidity, but as the air absorbs moisture, the temperature thereof must be increased to reduce the relative humidity to the desired level.

[0049] Thus for example the outside air stream 9A entering the enclosure interior might be at 25°C and a relative humidity of 30%. The exhaust air stream 9C might be at 35°C and a relative humidity of 30% which corresponds to about 60% relative humidity at 25°C. The exhaust air stream is thus carrying significantly more moisture than the incoming outside air stream 9A, and thus is carrying water out of the enclosure interior and causing same to dry.

[0050] The enclosure 41 illustrated in Fig. 5 shows a fairly large open space that is divided into nominal zones 47, as illustrated by the phantom lines, with an inside air unit 5B in each zone. The zones 47 are determined by substantially equally dividing the enclosure interior, and may also take into account areas that are wetter or drier than others. The zones 47 can be smaller where the area encompassed by the zone is wetter, and larger where the area is drier. The vent 42 can be located in a drier corner of the enclosure interior where slower drying could be acceptable. Those skilled in the art will recognize that various conditions can be considered when dividing the enclosure interior into zones.

[0051] The method of the invention provides increased efficiencies of operation, and reduced capital equipment costs. For example in the configuration of Fig. 5 the portable heat exchanger units 5 could each have a rated heat output of 65,000 BTU/hour, and the fluid heater could be a water heater with a rated maximum heat generating capacity of 800,000 BTU/hr. At initial start up of the portable heat exchanger units 5 in a wet building interior and where the outside relative humidity is high, the heat controller on each unit could be operating to direct all available heated fluid through the coil of each unit. There are 4 outside air units 5A and 10 inside air units 5B, for a total of 14. Each has a rated output of 65,000 BTU/hr for a total of 910,000 BTU/hr, while the fluid heater can only generate 800,000 BTU/hr. Thus the heated fluid at the supply port of the fluid heater will not attain the rated supply temperature, and each portable heat exchanger unit will operate at somewhat less than capacity, but drying will begin to take place. The desired relative humidity of, for example 25%, may not be attained in each zone immediately, and the air streams 9B may have a relative humidity of 28% instead, a level at which drying is still

effective.

[0052] As the relative humidity of the air in a zone begins to go down, the amount of heat drawn by the inside air unit 5B in that zone will be reduced, the supply temperature will rise, and more heat will be available where it is needed. As further zones dry and call for reduced heat, the inside air units 5B in those zones that are wettest will receive the maximum rated heat. Thus the system can supply the available heat to each unit 5B equally, and then, as more heat becomes available because of a reduced demand for heat in one zone, that heat is directed to those zones calling for more heat. A smaller capacity fluid heater 31 can thus effectively provide well distributed heat to dry the building interior.

[0053] The system may be configured such that the outside air units 5A have a priority by increasing the set point for the heat controllers at one or more of the inside air units from 25% to 30% so that the inside air units do not initially call for as much heat, and there will be sufficient heat available to reduce the relative humidity of the outside air streams 9A to the desired level of 25%. As the heat requirement goes down during drying, the set points can be changed to the desired level.

[0054] The set point for the desired relative humidity of the air streams 9A and 9B can be varied according to conditions from the typical level of 25% - 30%. Where materials are present in the space to be dried that are very sensitive to over-drying the relative humidity of the incoming air stream might be increased, and where over-drying is not a particular concern the relative humidity can be decreased.

[0055] The invention thus provides a method for controlling humidity in each of a plurality of zones of an enclosed space during a drying process. The method comprises in each zone, drawing air from the zone to create an air stream through a heating element and discharging the air stream into the zone; sensing the relative humidity of the air in a sensing location in the zone; in response to the relative humidity sensed at the sensing location, operating the heating element to raise a temperature of the air stream as required to reduce the relative humidity of the air in the zone to a desired relative humidity.

[0056] Conveniently the sensing location is located to sense the relative humidity of the air stream 9 after the air stream passes through the heating element 15, providing a direct measurement of the relative humidity of the air stream 9. A portable heat exchanger unit 5, 105 can be provided in each zone, with a humidity sensor 19 mounted on the portable heat exchanger unit to sense the relative humidity of the air stream 9 as it is discharged through the outlet 13, and a heat controller 17 operative to change the amount of heat energy supplied to the heating element 15 in response to the humidity signal.

[0057] The foregoing is considered as illustrative only of the principles of the invention.

[0058] Further, since numerous changes and modifications will readily occur to those skilled in the art, it is not desired to limit the invention to the exact construction

and operation shown and described, and accordingly, all such suitable changes or modifications in structure or operation which may be resorted to are intended to fall within the scope of the claimed invention.

Claims

1. A method of controlling humidity in each of a plurality of zones of an enclosed space during a drying process, the method comprising:

in each zone, drawing air from the zone to create an air stream through a heating element and discharging the air stream into the zone;
sensing the relative humidity of the air in a sensing location in the zone;
in response to the relative humidity sensed at the sensing location, operating the heating element to raise a temperature of the air stream as required to reduce the relative humidity of the air in the zone to a desired relative humidity.

2. The method of Claim 1 wherein the sensing location is located to sense the relative humidity of the air stream after the air stream passes through the heating element.

3. The method of any one of Claims 1 and 2 comprising drawing air from the zone to create an air stream through a heating element and discharging the air stream into the zone by providing a portable heat exchanger unit in each zone, each portable heat exchanger unit comprising:

a fan operative to create the air stream by drawing air from an intake and discharging the air through an outlet; and
a heating element located in the air stream.

4. The method of Claim 3 comprising sensing the relative humidity by providing a humidity sensor operative to sense the relative humidity of the air in the sensing location in the zone and operative to send a humidity signal.

5. The method of Claim 4 comprising mounting the humidity sensor on the portable heat exchanger unit in the zone such that the sensing location is at the outlet of the portable heat exchanger unit to sense the relative humidity of the air stream as it is discharged through the outlet.

6. The method of any one of Claims 4 and 5 comprising providing a heat controller operative to receive the humidity signal and operative to change an amount of heat energy supplied to the heating element in response to the humidity signal.

7. The method of Claim 6 wherein the heating element comprises a fluid coil connected to a fluid heater such that heated fluid from the fluid heater flows through the fluid coil, and wherein the heat controller is operative to adjust an amount of heated fluid flowing through the fluid coil from a maximum flow to a minimum flow.

8. The method of Claim 7 wherein the fluid heater is connected to the fluid coil of a portable heat exchanger unit in each zone.

9. The method of Claim 8 wherein a temperature of the heated fluid at a supply port of the fluid heater increases when the amount of heated fluid flowing through the fluid coils is reduced below the maximum flow.

10. The method of Claim 9 wherein the fluid heater has a heating capacity that is insufficient to raise the temperature of the air stream in each zone such that the relative humidity of each air stream is reduced to the desired relative humidity, and wherein when the heat controller on a first portable heat exchanger unit reduces the flow of heated fluid below the maximum flow, the temperature of the heated fluid at the supply port of the fluid heater increases.

11. A method of drying an enclosed space, the method comprising:

providing a plurality of portable heat exchanger units, each portable heat exchanger unit comprising: a fan operative to create an air stream by drawing air from an intake and discharging the air through an outlet; a fluid coil located in the air stream; and a heat controller operative to adjust a flow of fluid through the fluid coil; positioning at least one portable heat exchanger unit as an outside air unit with the intake thereof oriented to draw air from outside the enclosed space and with the outlet thereof oriented to discharge the air stream thereof into the enclosed space;
positioning a plurality of portable heat exchanger units as inside air units at spaced apart unit locations inside the enclosed space and orienting the intakes and outlets of each inside air unit to draw air from the enclosed space adjacent to the inside air unit and to discharge the air stream into the enclosed space adjacent to the inside air unit;
connecting the fluid coils of each portable heat exchanger unit to a fluid heater and circulating heated fluid from the fluid heater through the fluid coils and operating the fans;
sensing the relative humidity of the air stream created by each inside air unit; and

operating the heat controller of each inside air unit to raise a temperature of the corresponding air stream as required to reduce the relative humidity of the air stream to a desired relative humidity; and

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allowing an amount of air substantially equal to the amount of air drawn from outside the enclosed space to exhaust from the enclosed space.

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12. The method of Claim 11 comprising dividing the enclosed space into zones and positioning a portable heat exchanger unit in each zone.

13. The method of any one of Claims 11 and 12 comprising sensing the relative humidity of the air stream created by each inside air unit by mounting a humidity sensor on each inside air unit at a sensing location such that the humidity sensor is operative to sense the relative humidity of the air stream, and wherein each heat controller is operative to receive a humidity signal generated by the humidity sensor.

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14. The method of any one of Claims 11 - 13 further comprising sensing the relative humidity of the air stream of the outside air unit and operating the heat controller of the outside air unit to raise a temperature of the corresponding air stream as required to reduce the relative humidity of the air stream to a desired relative humidity.

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15. The method of any one of Claims 1 - 14 wherein the enclosed space is one of a building interior and a ship's hold.

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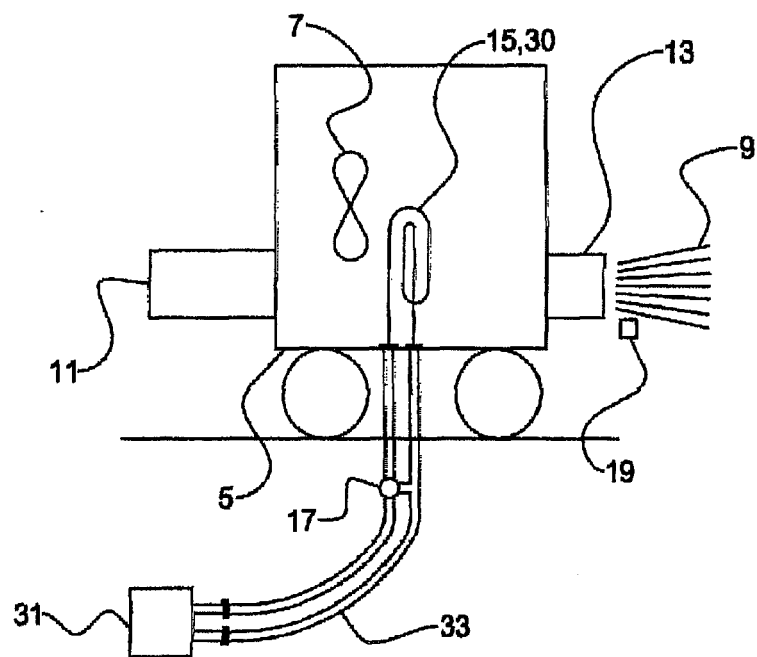


FIG 1

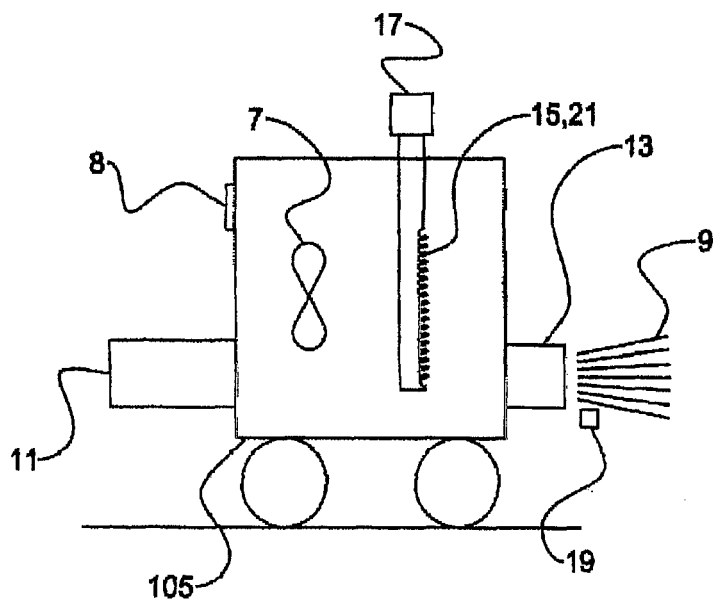


FIG 2

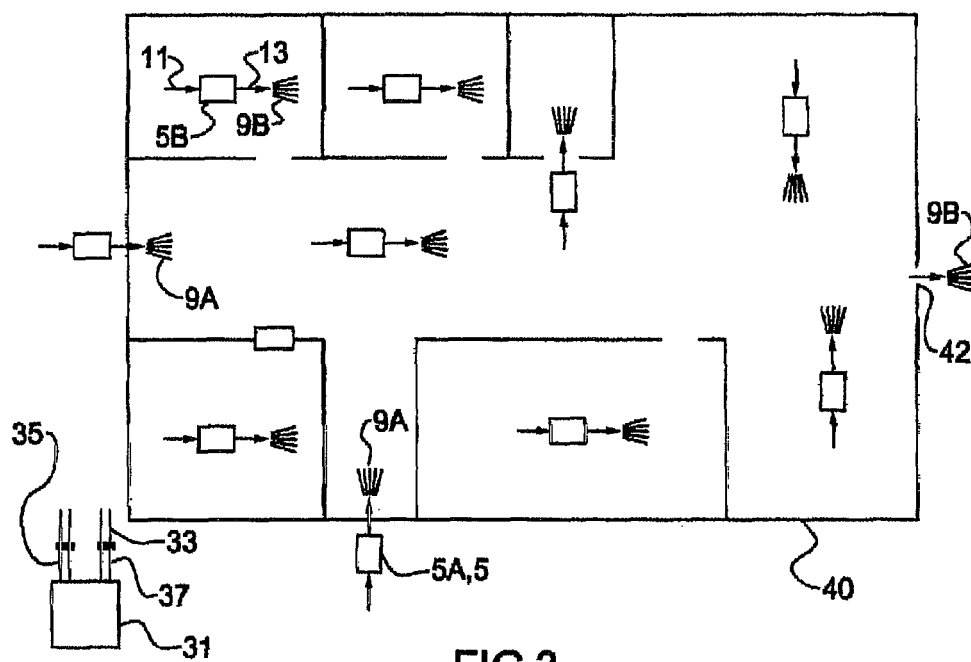


FIG 3

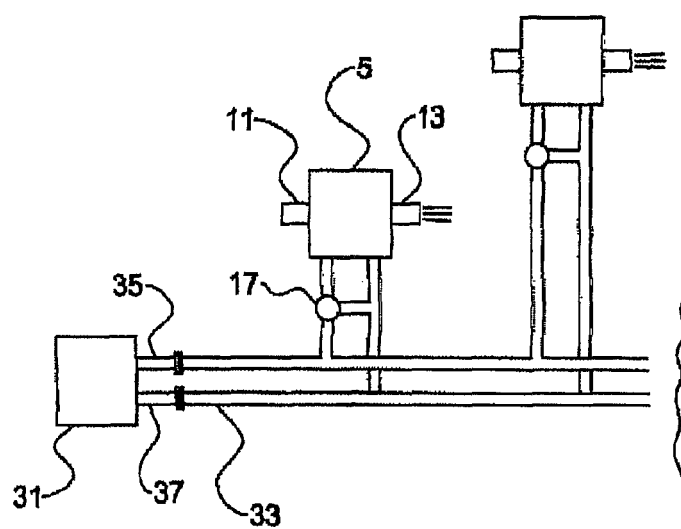
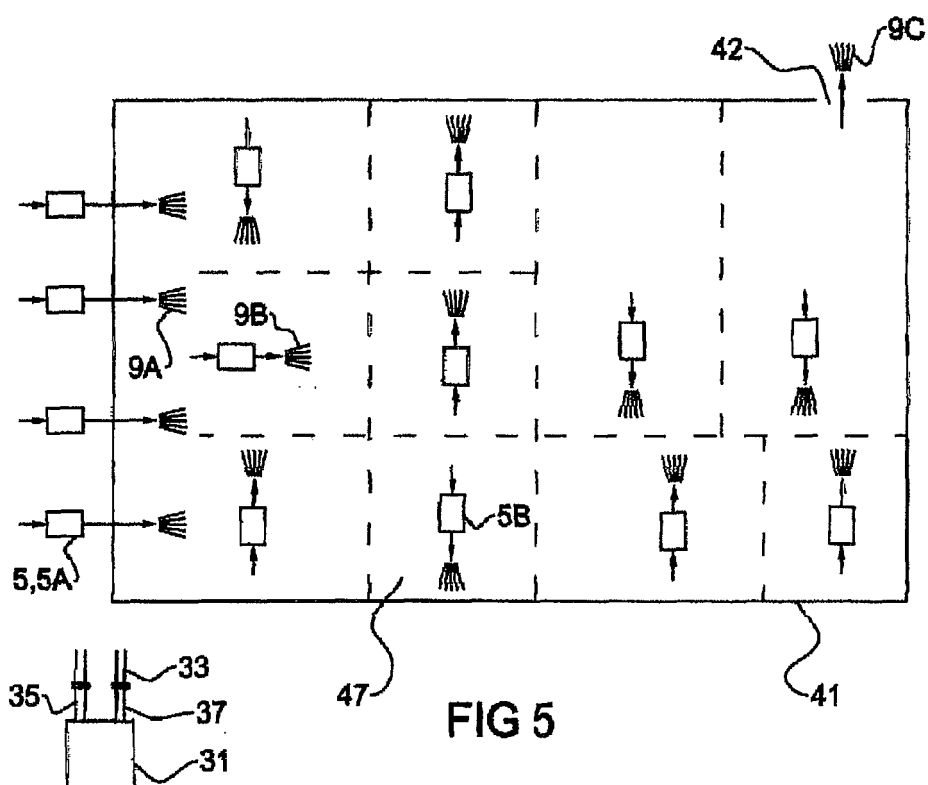


FIG 4



REFERENCES CITED IN THE DESCRIPTION

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