Conditioning Ventilation Air

for Improved Performance and Air Quality

The practice of using a mixing chamber for mixing outdoor and return air in a single system should be replaced by a technique with two systems: one providing thermal comfort, the other indoor air quality

By WILLIAM J. COAD, PE,*
Chairman of the Board,
McClure Engineering Associates,
St. Louis, Mo.

To provide good indoor air quality is the fundamental objective of every HVAC system. The definition for indoor air quality that will be used in this article is that good indoor air quality is the maintaining of the air in the space within the range of thermal characteristics and within the limits of concentration of chemical or organic contaminants necessary for human comfort and safety.

THERMAL CHARACTERISTICS

Thermal characteristics are those features of the space and air in the space that allows for the controlled rate of heat rejection from the human body, which is necessary for comfort and personal performance. The thermal characteristics include:

- Dry bulb temperature
- Relative humidity
- Ambient air motion
- Freedom from drafts
- Temperature homogeneity (air mixing)
- Radiant surface temperatures

Amongst other things, these characteristics are seen to be intrinsically related to the control of temperature and humidity, the method of introducing supply air into the space (the air distribution system), room surface temperatures, heat transfer dynamics between the space and the surroundings, and tightness of the construction.

CONTAMINANTS

Air is approximately 78 percent nitrogen, 21 percent oxygen, and 1 percent other gasses, including carbon dioxide, rare gasses, and airborne chemicals in molecular mix or suspension. Indoor contaminants or pollutants fall into one of three categories:

- *Category I; Contaminants generated within the space*—These contaminants generally have an identifiable source within the space. Examples would be carbon dioxide, biological odors and artificial aromas from the occupants; environmental tobacco smoke (ETS); volatile organic compounds from binders and adhesives; solvents and cleaners; chemicals from processes or storage; and cooking and food odors.
- *Category II; Environmental contaminants introduced into the space*—With these contaminants, one must identify first the type of contaminant and second its path into the space. The types would include such environmental pollutants as carbon monoxide, sulfur dioxide, industrial chemicals, solvents, and hosts of various types of particulate matter. The three most common paths into the space are 1) through purposeful envelope openings such as windows and doors, 2) through non-purposeful openings such as envelope leakage, and 3) through the outdoor air intake of ventilating systems.
- *Category III; Organic contaminants that breed within the space*—These contaminants are probably the most common, most harmful, and least understood. They thrive in environments of high relative humidity and moisture with favorable temperatures and materials or surfaces. The general forms of these contaminants are microbes, molds, and mildew.

Because these three categories of contaminants must be treated differently from one another in the design of an HVAC system, they will be identified in this article as Category I, Category II, and Category III pollutants, respectively.

Undoubtedly, closer attention to the problems of contaminants in the indoor environment would have evolved eventually without the energy conservation thrust of the 1970s. However, it was certainly spurred on by those activities. Two very significant aspects of the changes in building technology resulting from that event were the changes in the building envelopes, resulting in increasingly better thermal qualities and decreasing air leakage, and the use of variable air volume (VAV) systems for space temperature control to replace the constant volume terminal reheat and dual steam systems.

VENTILATION AIR*

The concept of the mixing chamber upstream of the space-conditioning apparatus as the point of introduction of the ventilation makeup air from the outdoors to dilute the Class I contaminants, properly designed and operated,

*William J. Coad, PE, is a member of HPAC Engineering's Editorial Advisory Board.

may have been a perfectly valid concept with the simpler systems of 50 years ago. However, in light of the complexity of today's systems, the concept is not technically sound. Today's buildings require multiple zoning, operating cycle turndown ratios varying from 100 percent of full load to zero on cooling and then from zero to 100 percent of full-heating load. The same system, in many cases, has to function at one time of the year in a hot humid climate and at another time of year in a very cold climate. If one analyzes the psychrometric control requirements under all of these varying conditions, it can be concluded that the very concept of the mixing chamber under these requirements is flawed. Furthermore, our continued reliance on this technology is a major cause of microbial (Phase III) contamination in air conditioning systems and, indeed, in air conditioned buildings. In many cases, lack of thermal comfort has simply been accepted as a limitation of air conditioning technology. And, these failures are certainly not a result of not spending enough money. The cost of the complexity introduced for the purpose of trying to make the mixing chamber concept work is overwhelming, particularly when compared to the lack of success of those efforts.

The question might then be asked, if the ventilation air is not introduced into the mixing chamber, where and how could it be successfully introduced?

** For purposes of this article, the following definitions apply:*
1) Ventilation air is air from the outdoors that is introduced to the space within a building for the purpose of diluting the contaminants to an acceptable level.
2) A humid climate is one in which the outdoor vapor pressure can be expected to exceed the design indoor vapor pressure for any appreciable time of the year.

THE ALTERNATIVE

Assume that a building to be air conditioned is located where the weather varies from hot and humid in the summer months (say, 95 F DB/78 F WB) to cold and dry in the winter months (say, 0 F), such as in the upper Midwest or eastern seaboard. Further assume that this is to be a tight building (very low infiltration), that the ventilation is to be independent from the control of any aspects of the space temperature, and that any and all dehumidification will not be done with the same device or system that provides the other thermal comfort requirements in the space.

SPACE TEMPERATURE CONTROL

Any HVAC engineer would agree that providing thermal comfort under such assumptions is really quite simple and inexpensive. It is simply a matter of an effective air distribution system and sensible cooling or heating in accordance with the following heat capacity equation:

$$q = (cfm)(1.08)(\Delta T)$$

where:

q = Sensible heating or cooling load, Btuh

cfm = Air circulation rate, cu ft per min

ΔT = Temperature difference between supply and room air, F

If this were to be done with a central fan system serving multiple zones of control, it could be done with a variable air volume system. The air handling unit could be as shown in Figure 1. The only control required would be a discharge thermostat controlling the cooling coil valve. Because dehumidification is provided separately, the coil

VAV System Problems and Solutions

Problem: Varying the velocity from a diffuser downward from its design value resulted in the creation of comfort problems, including:

- Poor air distribution
- Inadequate mixing
- Inadequate ambient air velocity
- Lack of temperature homogeneity
- Dumping of cold air

Solutions: In the form of products and systems, several alternative solutions have been implemented based upon product concepts. In many systems, two or more of the "solutions" are employed.

- Diffusers with a wider range of acceptable performance
- VAV combined with reheat
- Reset supply air temperature upward under part-load conditions
- False loading of space (thermodynamically—reheat)
- Other means for ambient air velocity and mixing (Casablanca fans, etc.)
- Series fan-powered terminals
- Parallel fan-powered terminals

Problem: A VAV system is a cooling-only system in most applications, thus varying the volume can only provide varying amounts of cooling. In climates where space heat is required, a heating capability must be added to the variable volume feature.

Solutions: The heating is usually achieved by combining the simple VAV concept with one of the constant volume variable temperature features. Some examples are:

- VAV combined with a reheat
- VAV combined with double duct
- Standing radiation for space heat or another stand-alone space heating system

Problem: Insufficient ventilation air available when VAV system is at less than full load. Since the mixing process provides a fixed percentage of outdoor air in the supply air mix, a reduction in supply air quantity to any given space results in a reduction in ventilation air.

Solutions: Several solutions have been proposed and used to maintain the quantity of outdoor air at not a fixed percentage but rather a fixed quantity. Some such solutions include the following:

- A control scheme that utilizes a fixed outdoor air opening and a sensor combined with a return air or fan speed control to hold a fixed negative pressure in the mixing chamber.
- Air flow measuring devices that sense supply air flow rate and return air flow rate and regulate the return air fan speed and/or damper positions to control a fixed quantity of outdoor air.
- An outdoor air injection fan combined with a flow measuring station that controls fan speed or damper(s) to force a fixed quantity of outdoor air into the mixing chamber.

could operate essentially dry and the leaving or discharge air temperature could be reset upwards to the temperature required by the zone requiring the most cooling.

The VAV terminals could have reheat capabilities to assist with the needs of the air distribution system, if necessary or to provide needed space heat in the winter months. A dynamic load analysis would reveal if such reheat would ever be necessary in any non-heating zones.

The system so described is a very simple and inexpensive system—from the air handling unit to the room control. It utilizes a minimum number of components and a minimum of control points and lines of control logic.

Other systems could, of course, be utilized with equal success and simplicity. Because the dehumidification and ventilation are not required, almost any recirculating system employing on-off or proportioned control logic will function quite effectively as long as good air distribution is maintained. Some such systems would be variable capacity diffusers, fan-coil units, unitary heat pumps, radiant heating or cooling panels, recirculating PTAC units, or many others.

The fact that all of these systems would provide sensible cooling or heating only, there would be no probability that an environment favorable for Class III contaminants would be inadvertently created (as is the case in *most* of today's systems).

This system, in whatever form, can be referred to as the space temperature control (STC) system.

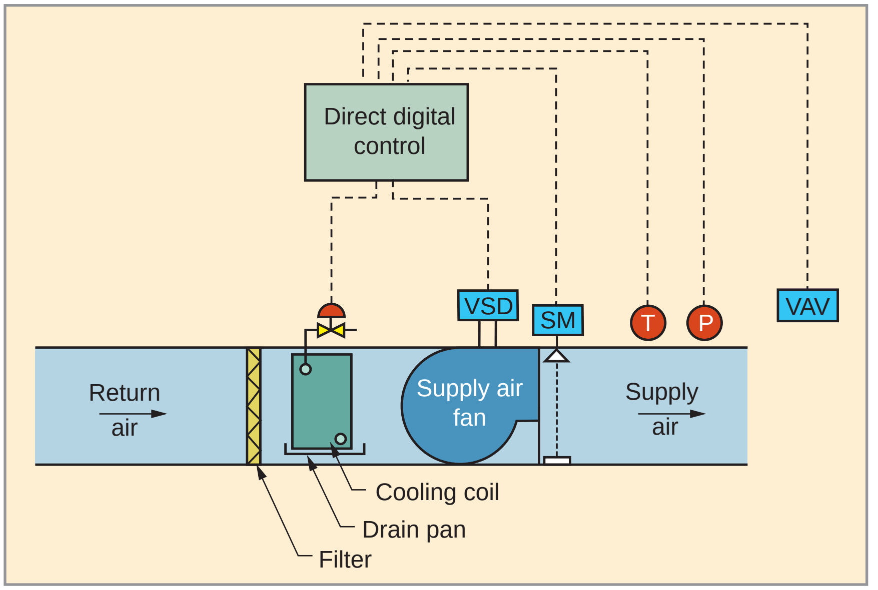

FIGURE 1. Space temperature control (STC) unit.

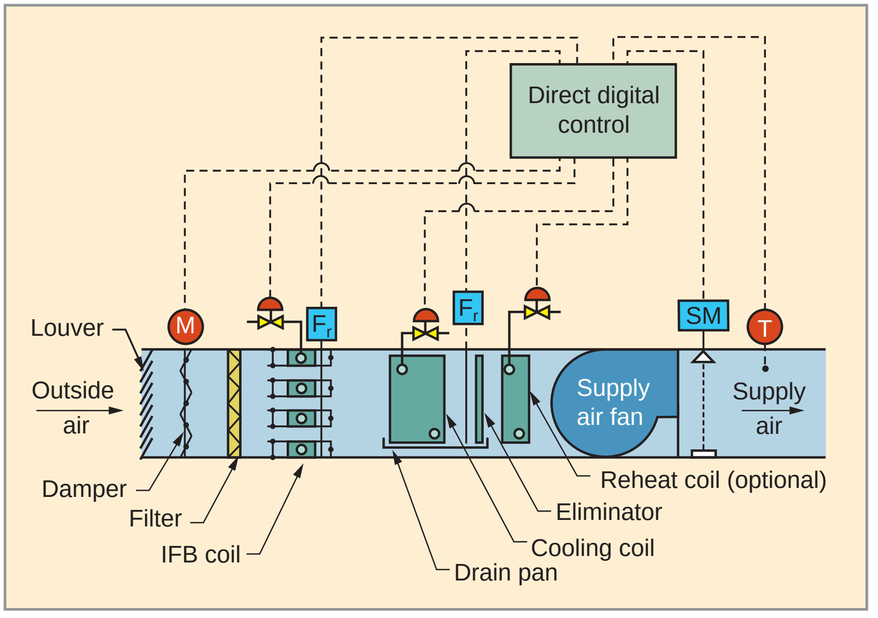

FIGURE 2. Ventilation air conditioning (VAC) unit.

HUMIDITY CONTROL AND VENTILATION

A theoretical analysis of the air conditioning problem for today's buildings in humid climates reveals an intrinsic link between the conditioning of the outdoor ventilation air and control of the indoor humidity (and the resulting prevention of microbial growth).

Consider the following logic for buildings located in a humid climate.*

- In the vast majority of buildings, the major source of indoor water vapor is from the outdoor air.
- If the outdoor air could be prevented from entering into the space untreated, the only latent load would be water vapor generated within the space.
- Assuming a "dry" space, the only source of the water required for microbial growth would be from water vapor introduced, in some way, to the space.
- If no water vapor is introduced into the space, and the vapor that is generated within the space can be absorbed by dry air being introduced into the space, there would be no moisture to support microbial growth.

Therefore, in a warm and humid climate, no air from the humid outdoor surroundings should be allowed to enter the cooler space until it has been properly dehumidified. And in this context, properly dehumidified means reduced in moisture content to a dew point at or below that at which the space air is to be maintained. Because the ventilation air is from the outdoors, the conclusion is that any and all outdoor air introduced into the building should be dehumidified to a specific humidity level (dew point temperature) at or below that which is desired within the space. *This is the intrinsic link between conditioning of* *outdoor air and space humidity control*.

In the preceding paragraphs that discussed space temperature control, the hypothetical condition was established that in designing a system to provide environmental comfort it was assumed that the ventilation requirements and humidity control would be handled as a separate consideration. The companion step, then, is to provide that requirement.

The thesis then proposes that the recirculating space temperature control (STC) system(s) be supplemented with another air handling and distribution system that has the following design characteristics:

- Introduce all outdoor air at this unit in an amount necessary to satisfy the ventilation requirements of the space.
- All air that enters the building is introduced through the ventilation air conditioning (VAC) unit.
- All air introduced through the VAC unit in warm, humid weather must be dehumidified to or below the dew point temperature desired in the space.
- If the space is to be humidified in cold (dry) climates, all humidification should be provided at the VAC unit.
- Removal of the particulate and unwanted chemicals from the outdoor air, if this is necessary, should be accomplished at the VAC unit.

The ventilation air conditioning unit would then in its fundamental configuration take the form of the unit in Figure 2. This is an example of a unit for a system with chilled water and heating water available; constant volume ventilation requirements; reasonably small-space latent loads; and no winter humidification. Assuming that a separate duct and air distribution system is used to deliver the design quantity of ventilation air to each space, the unit only need be sized for the sum of the ventilation air required, in absolute quantity, to each space. From both the size of the ventilation system and the energy required to condition the air, this is the smallest capacity, most energy-efficient ventilation system that could be provided for a building.

Another germane feature of this unit is its simplicity. In its basic form, the unit is on-off, the intake damper is open-closed, and a freeze protection control is required, but it is quite simple—either the preheat coil is heating or it isn't. The only modulating controls are for the preheat coil and the cooling coil, and simple proportional control is perfectly acceptable because except at startup, no upset will occur more rapidly than changes in the outdoor temperature.

This relatively small unit is the only place in the system where the psychrometric problem is solved: it is also the only point at which two-phase phenomena occur, and thus the only place at which microbial growth could be supported. In the design of these systems, it is recommended that all possible precautions be taken to assure cleanliness (near sterility) in the casing of this unit. Locating the fan in the draw-through position will provide a little reheat to assure that the air leaving the unit is incapable of being supersaturated, thus providing no opportunity for liquid formation or accumulation within the supply ductwork or the space.

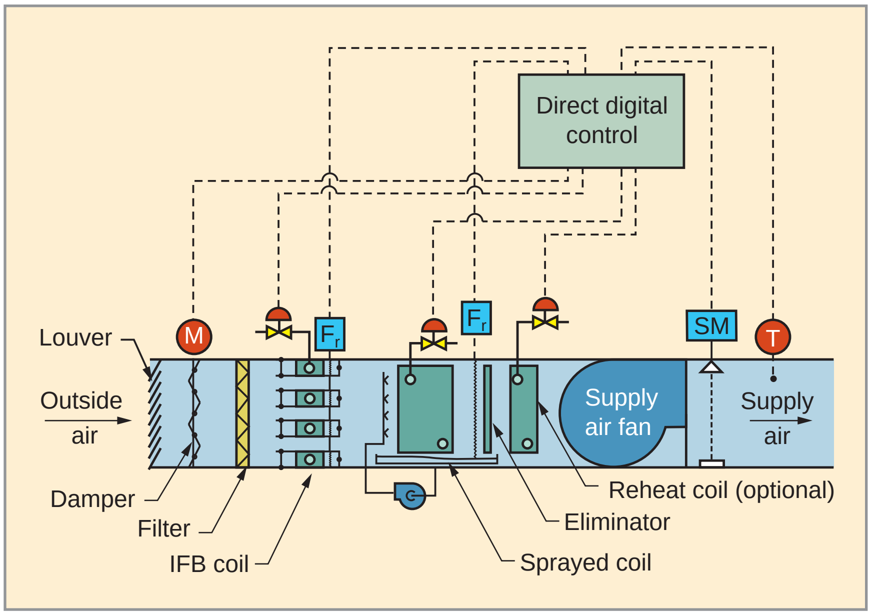

FIGURE 3. Sprayed coil VAC unit.

THE DISTRIBUTION SYSTEM

In its simplest form for most buildings, a reasonably small capacity ducting and distribution system from the VAC unit supplying the treated air directly into each space is all that is required. In those cases in which the combination of the air quantity and the space geometry are suitable, the ventilation air as it is introduced may be adequate to provide the ambient air motion needed for thermal comfort. One manufacturer of variable flow supply diffusers provides a constant flow outer nozzle for just this purpose. Also, in those applications where the small amount of sensible-load capability carried in the makeup air could exceed the sensible space load, reheat could be used, but this is usually not the case on a dehumidifying cycle.

Another option, in those cases in which a single VAC unit is combined with multiple STC units, is to supply the air from the VAC unit into the return air stream of the STC unit. There are two disadvantages to this choice.

- The quantity of outdoor air required may increase because of the multiple space syndrome, *i.e.*, the room needing the highest percentage of outdoor air will now drive the percentage at the point of mixing.
- The sensible-cooling capacity of the ventilation air cannot be added to that of the recirculated air to reduce the STC unit air flow requirements.

But, except for the possible energy impact of the first disadvantage, these are both cost considerations that could be traded off against the economics of the separate distribution system.

ALTERNATIVE CONFIGURATIONS OF THE VAC UNIT

In climates where the winter outdoor temperature is significantly below freezing, many designers feel more comfortable using an integrated face and bypass heating coil. Although, when hot water is used for heating, a pumped heating coil with varying water temperature is quite acceptable with a properly circuited coil.

Where direct expansion refrigeration is used in lieu of chilled water, constant dew point temperature can be achieved by various methods of controlling the system back pressure or false loading with hot gas bypass. However, if only an upper limit on relative humidity is the concern (environmental comfort), staging compressors or compressor-capacity control has proven effective.

Furthermore, the VAC units are perfect applications for a host of energy conservation cycles such as reheat/precool run-around coils, ventilation intake/exhaust heat recovery, etc. They are also well adapted to the various techniques of desiccant cooling and evaporative cooling in either simple or compound cycles.

The concept being presented is not new or revolutionary. It was born in those HVAC applications in which close-tolerance temperature and humidity control was a fundamental design parameter. And, the solution provided by this concept is elegant. If the application requires a constant relative humidity and dry bulb temperature at all times (art museum, computer room, laser laboratory, etc.), the VAC unit can simply be modified by providing a sprayed coil unit in place of the cooling coil (Figure 3). Then, with no control system changes, it will become a humidifying or dehumidifying conditioning device simply by the laws of physics. If there are measurable internal latent loads, a space humidistat could be used to reset the dew point control temperature as needed, but this is seldom necessary.

This type of humidifier cannot supersaturate the air to the space. This supersaturation, quite common with many humidifying systems, is a *major* cause of Category III contaminants.

NO AIR ECONOMIZER

With the system configuration being proposed, there is no assumption of an air economizer for winter cooling with outdoor air (or partial cooling such as with an enthalpy economizer). Analogous to the mixing chamber, the use of an air economizer has been assumed as almost a "given" by generations of HVAC system designers. Ethically, it seems to be wrong to waste energy refrigerating a space when the surroundings are at a temperature lower than the space; stated another way, to refrigerate recirculated air for cooling when it can be simply replaced with colder outdoor air for the same cooling. But, this will be the subject of a future article. Suffice it to say, not only have studies revealed that many air economizer cycles are not economically justifiable, but there have been many cases, not only where they added to the investment cost, but they actually consume *more* total resource energy than the alternatives.

COST OF INSTALLATION

The immediate reaction of most HVAC practitioners (be they contractors, engineers, or owner/facility managers) is that the use of two units or systems (the STC and VAC systems) must be more expensive than a single system to serve both functions. This is not the case.

From a logic perspective, if the VAC system is design properly, the recirculating STC unit operates dry, providing sensible cooling only. Thus, at this unit, there should be no danger and thus no concern for creating an environment that encourages microbial growth. This then becomes a simple, inexpensive air handling unit with no problems of freeze protection or damper interlocks. Furthermore, if the VAC unit discharge air is ducted directly to the space, the STC unit is smaller by the amount of air provided by the VAC unit. Also, the STC unit has a much lower pressure drop than a more "conventional" unit because it doesn't require pressure losses through the mixing dampers, preheat coil, eliminators, wet cooling coils, and filters designed to remove atmospheric impurities. Being able to reset the sup-

Mixing Chamber

A mixing chamber is a device added to an air conditioning air handling unit to add the feature of supplying conditioned ventilation air to the space simultaneously with the conditioned recirculating air required for space temperature and humidity control.

Problem: Introducing the ventilation air through a mixing chamber in a multiple-zoned air handling system introduces several problems or limitations on the system design options. Examples of these are:

- When multiple spaces are supplied by the air handling unit, the single space with the requirement of the highest percentage of outdoor ventilation air will establish the outdoor air/return air percentage mix in the mixing chamber.
- In warm humid climates where the outdoor-specific humidity exceeds the indoor-specific humidity, the mixing chamber will humidify the recirculating air.
- When the above occurs in a unit with on-off control or bypass control, the system will humidify the space.
- In cold climates, if the indoor space is humidified, destructive condensation can occur in the mixing chamber as the mixed air drops below the dew point temperature of the indoor air.
- If the outdoor specific humidity exceeds the indoor specific humidity, all of the air (ventilation and recirculated) must be cooled below the design dew point temperature to maintain space humidity control.
- If there are chemical pollutants in the outdoor air requiring chemical filtration, the chemical filter must be sized to filter all of the air (ventilation and recirculated) since it is normally installed downstream of the mixing point.
- In cold climates, steam or water coils in an air handling unit can be subjected to below freezing temperatures and must be protected from freezing and rupturing. This protection often results in less reliable performance of the unit whether from actual safety shutoffs that protect the unit or nuisance shutdowns because of anomalies of the system. (When the air handling unit is used to heat the space, a freeze-protection shutdown turns off the space heating system.)

ply air temperature upward under part-load conditions without reheat, in many cases, will provide effective part-load control without terminal reheat, fan-powered terminals, or other costly, complex, and potentially troublesome terminal device schemes.

Experience in applying this concept to actual installations has been that the systems have been installed within the same budgetary constraints as more "conventional" systems and sometimes for considerably less. In one of the more spectacular examples, in a large medical building in the Midwest, the HVAC system cost was reduced by 31 percent, accompanied by an estimated reduction in annual energy cost.

CONCLUSION

The thesis presented in this article is that in warm, humid climates or cold climates the use of an outdoor air-return air mixing chamber upstream of the air handling unit is a concept that is fundamentally flawed, and the practice should be replaced by the alternative concept presented. That concept is to provide basically two systems to provide reliably for 1) the thermal comfort and 2) assurance of acceptable indoor air quality. The VAC system should be a 100 percent outdoor air system and provide all of the ventilation air required. It should be the *only* point at which outdoor air is introduced into the building as well as include particulate and gas filtration to remove Category II contaminants (if this is necessary) and provide all of the space humidity control.

The STC system should be designed and arranged for sensible heating or cooling and for control of the thermal comfort aspects of the space *except* the humidity level. All humidity control should be delegated to the VAC system. The STC system could provide the ambient air velocity, or this feature could possibly be provided by the introduction of the ventilation air into the space or by other means (such as a Casablanca fan or other in-the-room circulators).

Properly designed systems based upon the concept proposed, would provide an extremely high degree of indoor air quality and thermal comfort for general space conditioning or for spaces with extremely critical requirements for close-tolerance control of temperature and humidity, at a reduced installation cost.

Insofar as adequate and measurable quantities of ventilation air necessary to control Category I contaminants is concerned, the VAC system provides a single and easily measurable and controllable point of introduction of ventilation air.

With the concept proposed, providing good indoor air quality by design can be a proactive and planned engineering achievement rather than a reactive response to problems. **HPAC**

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