UFAD Systems White Paper

Under Floor Air Distribution (UFAD) systems have a number of advantages when compares to traditional overhead VAV or fan coil systems.

From our customers, the most frequently reported benefits are:

1. Improved Flexibility for building services
2. Achieve cost effective LEED certification
3. Improved Ventilation Efficiency and Indoor Air Quality V_E=1.2
4. Improved Occupant Comfort, Productivity and Health
5. Reduced Energy use- Less fan hp, Extended economizer cycle
6. Reduced First cost and Life-cycle costs
7. Reduce slab-to-slab heights and façade costs

Once the decision had been made to use a UFAD system, one of the next choices is to determine how much of the occupied floor space should have VAV, and should manual control diffusers be considered in some areas. The base recommendation from AirFixture is to use VAV in all areas of the building, all the time.

Here are the reasons:

1. VAV is better, and the first cost premium is small (compared to manual control options).
2. VAV systems will provide better comfort to users – the most financially important benefit.
3. VAV systems will adapt to expected or unplanned changes in occupancy, building loads and primary conditioned air temperature. Easier, safer for designers.
4. VAV systems controlled by intelligent thermostats or Building Automation systems have a better chance of saving energy.
5. VAV systems do not require manual adjustment or balancing, but manual control is a low cost added option on VAV diffusers, and adds further flexibility on some applications.
6. Most VAV diffusers have an acoustical boot on them. This boot provides acoustic isolation from nearby offices or cubicles that does not happen with manual control diffusers.

These reasons are supported in detail as follows:

1. VAV is better and the first cost premium is small (compared to manual control options). Most of the buildings we see using UFAD systems have midsize to small floor plate size. We do have some UFAD examples with floor plates larger than 50,000M^2 but these are very uncommon. Most of the buildings built today have floors of 2500 M^2 or smaller. Let's consider a "thin" building. Many times LEED certified buildings are thin rectangles or assemblies of thin rectangles. This geometry provides better daylighting

deeper into occupied spaces and generally more attractive buildings. The building foot print is more likely to be 20M x 125M than a square 50M x 50M.

If the 2500M^2 building floor plate is 20M in the small dimension, it is reasonable to expect that the outer 5M (all 4 sides) is a perimeter zone. Perimeter zones are always required to have VAV, thermostatic controlled systems. So from the beginning, 1350 M^2 has to be VAV. Of the remaining 1150 M^2, it is likely that 500M^2 is devoted to core areas for elevators, bathroom, air handling, air shafts, stair wells and electrical rooms. So, in this example only 650M^2(26%) may be available as area that could be conditioned by VAV diffusers or manually controlled diffusers. Manual diffusers are only attractive because of their low first cost. There is no benefit of a manual diffuser that is not included in a VAV diffuser with manual option. Interior zones are candidates for manual diffusers because: interior loads are 3-5 times less than peak perimeter zones; and interior zones are not as variable as perimeter zones (principally because of solar radiation). Building loads and loads created by occupancy vary tremendously because of building construction, type of occupancy, and climate. Modern buildings may have very good infiltration control, well insulated walls and high efficiency glass, but executives and other occupants lucky enough to be located at the perimeter, still like to look out of, and have sun shine in, their windows. Perimeter cooling loads commonly vary from 27 to 55 M^3/hr/M^2 (average 37). Interior zones typically vary from 5 to 13 M^3/hr/M^2 (average 9). With these average values and our sample size floor plate the perimeter zones require 4590 M^3/hr and the interior zones require 585 M^3/hr. If the perimeter and core area diffusers are the same size, only 13% of the diffusers could be manual control. In North America, a VAV UFAD - 255 M^3/hr floor diffuser sells for about $225usd to a contractor with freight and control wire. A same size manual diffuser costs about $100usd.

So consider the cost difference:

	All VAV System				VAV and Manual system	
	Quantity	Contractor cost	Install labor	Total	Quantity	Total
VAV diffusers	220	225	20	53900	195	$ 47,775
Manual diffusers		100	15		25	$ 2,875
Thermostats	12	225	60	3420	10	$ 2,850
				$ 57,320		$ 53,500

Less than
10% Cost
difference

Of course all buildings are different and you need to consider the proportions for the shape and size of your building. Another way to put this into perspective is to look at the cost of adding all VAV on a "% of total construction cost" basis. In the example above the added cost of all VAV was $1.53 per square meter (of the whole floor plate). It is very likely that the construction cost of the building is $1500-2500 per square meter. This addition of VAV in interior zones amounts to 1/10th of 1%.

2. VAV systems will provide better comfort to users – the most financially important benefit. The most expensive part of a building's operating cost is the PEOPLE working in the occupied space. In a study prepared for a US company the results were:

Using a standard international Building Council average people density of 143 ft^2/person and using an average salary of $75,000USD per employee;

>Average energy cost for a medium sized office building is $1-2 USD per ft^2 per year.

>Average construction cost (amortized 20 years, w/ interest) is $20USD per ft^2 per year.

>The average people cost is $525USD per ft^2 per year.

The point of these numbers is that: anything we as designers can do to improve the "Facility Environment" that improves the efficiency of the PEOPLE in the building, is far more important than energy cost or the first cost of construction. We submit to you that Raised access floors and UFAD have a positive and measurable impact providing a more efficient and effective Facility Environment.

The FACILITY ENVIRONMENT includes:

Security	Fire & Life Safety
Lighting Control	Dining & Restrooms
Temperature Control	Humidity Control
Ventilation Control	Power & Com Utilities
Voice Privacy	Comfortable Acoustic Environment
Flexibility for Moves & Changes	

The most basic thing that a VAV diffuser does, that a manual controlled diffuser cannot do, is automatically adjust itself to adapt to changing air temperatures below the floor (that happen every day) and changing loads in the occupied zone (that happen every day). These changes (UFAD air temp and loads) often move in opposite directions from what would be desirable.

The air temperature under a raised floor in a UFAD system is often set at 17°C at the discharge from the duct from the central fan coil or Air Handling Unit (AHU).

Depending on many factors:

- distance from the outlet,
- duct velocity at that time,
- AHU setpoint,
- chilled water reset,
- delay in AHU controls,
- cooling load above the floor,
- cooling load in the ceiling of the floor below the one we are considering,
- blockage of air flow under the floor
- temperature of slab during a morning start-up

Changing Conditioned Air Temperature - As a result of these factors, the air under the floor at a sampling point should be expected to vary from 17°C to 23°C on an average day.

Changing Load above the floor - The inter zone load might change from an unoccupied cubicle; then at 8:00am to a cubicle with 2 people, laptops and task lighting in a few minutes.

With loads changing above the floor, and conditioned air changing temperature below the floor, how could a fixed airflow rate (from a manual diffuser) provide a constant temperature environment? Quite simply it cannot. The occupied space temperature will change several degrees depending on the factors above. We believe it is very unlikely users will adjust their diffusers after the first few weeks moving into a facility. When a company and employees move into a new facility it is very exciting, a new beginning. Frequently they have moved from a poorly air conditioned space. Bad air conditioning is still among the top reason tenants move out of a location. We believe that it is a natural expectation of tenants to get automatic thermostatically controlled air conditioning systems when they move into a shiny new building. It is unreasonable for the unlucky ones to be expected to get down on their knees to improve their comfort. Even if they are educated how to make these adjustments, they are very unlikely to do this every few days as will be needed to achieve comfort. And what about the distraction of being hot or cold? This costs the company valuable time and money.

3. VAV systems will adapt to expected, or unplanned, changes in occupancy, building loads and primary conditioned air temperature. Easier, safer for designers. Many times I have been involved in the commissioning of a building where we have difficulty controlling humidity, building pressurization or balancing airflow because the building is operating at a condition that the designers did not anticipate, like 20% occupancy on a

cool rainy day. Sometimes it is even worse; we have a hot weather start-up with a fully occupied building. In some cases certain floors were planned for open office, now these are all conference rooms. Executive floors become open office because a particular lease did not get signed. VAV systems can adapt to all of these conditions is there is sufficient capacity at the AHU coil. It would be hopeless to expect a manually controlled system to adapt to these changes. A major facility in Kansas City had a large area served by 4 large AHU's 1,2,3,4. #2 AHU had a motor failure during a high occupancy summer day. The building operators had to execute a plan to keep the facility ventilated and comfortable with one AHU down for several days. What they did was to lower the leaving air temperature from units 1,3,4 and allowed the 3 AHUS to speed up to maintain design floor pressure. Because supply air temperatures were lower than design, diffusers close to the AHU discharge had to modulate a bit more closed to maintain space temperature. Diffusers in the zone #2 had somewhat warmer supply air (because the air travelled farther under the floor) and had to modulate more open, and stay open longer to maintain comfort in the occupied space. The facility continued to operate at nearly full capacity. After the AHU was fixed, the building operators returned settings at the AHUs back to design and the 1000 diffusers AUTOMATICALLY adjusted to the changes without any operator intervention. This would have been completely impossible with a ducted system and practically impossible with manual control diffusers.

It is also fairly common that the final user of the building uses, or tries to use, the building in a way that was not part of the instructions during the design. Sometimes the window glazing does not perform as planned and the sunny side of the building has a higher load density than planned. Sometimes the contractor is not the highest quality and the building envelope leaks more than the Cooling load predicted. Perhaps the tenant has a lot more computer loads, more people or smaller workstations than anticipated. A VAV UFAD system can AUTOMATICALLY adapt to these changes. So long as cooling capacity is available the UFA Distribution system can adapt without costly rebalancing to the building use. If you have enough Tons and a VAV UFAD system, the building will perform making the designers look good. It is the most conservative design.

4. VAV systems controlled by intelligent thermostats or Building Automation systems have a better chance of saving energy. This is a simple one. If everybody comes to work at the same time every day, has the same absentee rate, has fully occupied space and goes home at the same time, a building could be turned on and off with a light switch. Of course none of this is possible. When accounting department works late every day, the sales department is mostly out of the office and the HR department works short days, each of these departments can have their HVAC system turned off by zone according to a BAS system schedule or smart thermostat. Taking this one step

further, motion sensors can (and should) be added to zone thermostats shutting off (or setting the temperature back) all diffusers saving cooling and fan energy. What happens when we have 2 large interior zones on one AHU with manual control diffusers? If zones 1 has an 8 hour / 5 day schedule and the other zone 2 has 4 day 12 hour shifts we will be forced to waste a lot of air horsepower and cooling tons. And what happens to those unoccupied spaces with manual diffusers? They become freezing cold. You would be amazed how many facilities operate this way. Of course a VAV system would shut off unoccupied zones, prevent over cooling and save a lot of operating energy and cost.

When I was last in Brazil I toured a facility near Sao Paulo, (Alphaville). After meeting with the engineer for the project and reviewing the electricity charges (costs) for the facility, I discovered just how costly power is in Sao Paulo. At this particular commercial facility the lowest off season, off season, off peak power cost was .52$R per kwh and the highest was over about .92$R/kwh.

At these high power rates more aggressive energy saving strategies will pay back the first cost investment very quickly. I am sure others are aware of this in their respective system specialties. Surely high efficiency chillers, efficient lighting systems and advanced control systems are in widespread use. This article is focused on optimizing modern UFAD systems for the best financial return on investment. With high power costs, the most efficient energy saving strategies will likely be the best investments.

The most obvious and simple strategy with UFAD systems is to employ "demand controlled" control strategies. Don’t have the system operating unless there are people in the space to benefit from the conditioned environment. Turn the air off when not really needed.

A system that is turned off will usually save the most energy and money, but not always.

There are two exceptions I need to mention related to HVAC systems. Energy saving strategies that sacrifice comfort and effect productivity of the building occupants should not be used. While some energy can be saved, the cost of lost productivity of the people will probably be 10 to 20 times greater than the energy saved. So, sacrificing human comfort for energy savings is a losing strategy. The second exception to the strategy of "turning systems off" is commercial building pressurization. Unless you are considering a facility in a very dry climate, Moisture Intrusion into the unoccupied buildings during "off" cycles has the potential to cost more and cause more damage than the small amount of energy it takes to maintain a pressurized building. Mechanical engineers understand that vapor pressure is the true driver of moisture penetration, but pressurization of buildings, controlling moisture laden infiltration, has proven to be an effective means of maintaining interior air conditions such that ASHRAE recommended humidity levels can be maintained (for human comfort, Standard 55). Additionally moisture penetration into internal building materials will still require energy to remove it during occupied cycles. Just consider the building as a big sponge absorbing moisture in off cycles only to require more peak energy to remove that moisture during occupied cycles. Additionally water vapor can condense inside construction materials in very undesirable locations in commercial buildings. The resulting mold growth can be devastating to a facility and its occupants.

With UFAD systems there are three basic ways to design "Demand Controlled" systems so that they only operate when cooling (or heating) is needed for occupant comfort:

a. Turn off the primary AHU or fan coil in the whole zone (when un-occupied)
b. Use fan powered boxes or fan powered diffusers, turn off in local zone
c. Use simple VAV diffusers, each diffuser has a damper, turn off in local zone

a. The difficulty with having the AHU as the only means of cycling off the airflow is that the zone is likely to be very large. This means that a large number of people have to be on the same work schedule, a very unlikely circumstance. What is likely is that when a large zone is cycled off for saving energy, space conditions will be uncomfortable, unhealthy, or someone will over-ride the system turning it back on. Alternatively, a large number of small AHUs can be used. This (lots of small AHU's) has a high first cost, a high ongoing maintenance expense and is not flexible for future relocation of utilities or offices.

b. A variable speed fan powered box mounted under the floor and connected to several constant volume or adjustable volume diffusers is an effective means of modulating the cooling airflow (or turning the air off in unoccupied mode) to a zone in response to a space thermostat. The problems with these systems is that the underfloor ducting and the fan box itself, significantly block the underfloor plenum and make it less useful for running other utilities like voice, data and power wiring.

Fan powered diffusers are another means of controlling the airflow to zones. When connected to a BAS controlled thermostat they can effectively operate in VAV mode during occupied mode and cycle off by zone in response to a schedule or an occupancy sensor. The disadvantage of fan powered boxes or diffusers is: that they cost significantly more than simple (low voltage damper style) VAV diffusers; the make noise; they vibrate; they require maintenance; and each one requires primary (usually 220v) power. They are expensive to install and they are difficult to relocate. Many of them have ridiculous proprietary controls with no field support.

There is a myth that exists in the old UAFD design community that somehow fan powered diffusers are needed in perimeter zones. This is completely false and the fan is usually a dis-advantage for the reasons stated above. Fans in diffusers might have made sense 25 years ago when it was widely believed that it was not reasonable to expect construction teams to construct an air plenum under a raised access floor. In the present day (since 2001) millions of M^2 of pressurized plenums have been successfully constructed all over the world, in every type of culture, climate and building type.

The conclusion is that is much more practical and cost effective to construct an air tight plenum that will contain low pressure (12pa) conditioned air. This eliminates the need for hundreds or thousands of small inefficient motors to move conditioned air into the occupied space. Highly efficient centralized AHU's with VFD's deliver that air for lower first and lower operating cost. In the recent ASHRAE UFAD design guide published in 2013, numerous varieties of these systems are explained in detail. In the energy consumption chapter, evidence is presented documenting a 5% energy penalty for fan powered diffusers when compared to simple VAV diffusers. Stated directly, fan powered diffusers cause a building to waste about 5% of the HVAC system energy.

c. Use simple VAV diffusers, each diffuser has a damper, turn off in local zone. This method of delivering air to occupied spaces is by far the most widely used UFAD system in the Americas, and most of the world. Simple, lower cost diffusers with an integral 24vac damper modulate to control environmental conditions in today's modern commercial buildings. These diffusers do not make noise, and operate for a lifetime without any maintenance except cleaning. They are easy to install and re-locate, and cost about 1/3 as much as a fan powered diffuser. Thermostatic Zones can be created in any size from 1 to 1000 diffusers, but the average is about 8-10diffusers per thermostat in perimeter zones and 15-20 in interior zones. Zone thermostats with "PIR" will definitely save a lot of money and energy. If done intelligently, this can be done with negligible effect on comfort. This topic has been widely analyzed and **savings of 28-50% are reasonably possible** depending on many, many variables (see the table below from MGE and the attached study on this question. But it is important to note that to achieve significant savings one must have VAV diffusers and BAS connected thermostats. That is why we recommend all VAV, all the time, everywhere. It will be the low life cycle cost system in nearly every application.

COMMON AREAS OF APPLICATION WITH BENCHMARK SAVINGS

- **Corridors & Staircase** – 30% - 80%
- **Basement Parking Areas** – 70%
- **Restrooms & Toilets** – 30% - 90%
- **Conference Rooms** – 22% - 65%
- **Office Cabins** – 13% -50%
- **Storage Areas** – 45% - 80%
- **Open Plan Office** – 20% - 28%
- **Auditoriums** – 40% - 46%
- **Canteen & Common dining areas** –"Not Available"
- **Lift / Elevator landing Lobbies** – "Not Available"

Data Source: Madison Gas & Electric Co – www.mge.com

5. VAV systems do not require manual adjustment or balancing, but manual control is a low cost added option on VAV diffusers, and adds further flexibility on some applications. In a properly constructed UFAD plenum of reasonable size, there is no pressure differential. Are you surprised? I was, till I proved it to myself. The theory is that a plenum works just like a pressure vessel or the Goodyear Blimp. When a relatively small release (think 1/200th) of the plenum volume occurs, that out flow is replaced by inflow elsewhere, and the overall pressure of the plenum does not change. I walked around a 9000M^2 UFAD project where hundreds of the same diffuser were installed. All of them had the same airflow as measured by a high quality flow hood I was using. We repeated these at different pressures and the same held true. Certainly you can create a pressure difference with extremely high flows, flow blockages and other anomalies, but these are very uncommon. VAV UFAD diffusers do not require any balancing or adjustment. They all have the same inlet pressure, and they modulate the airflow to that which is locally required to hold set point. No need or reason to balance them. If the engineer calculates a 133cfm cooling load a 150 cfm diffuser will work perfectly. It will throttle to 133/150= 89% or it will be open to 150cfm 89% of the time.

Virtually all UFAD VAV diffusers can be fitted with some form of user adjustable volume adjustment. For many manufactures this is inherent in their design or can be added for about $10usd. We need to destroy another old time UFAD myth, only manual controlled diffusers are user adjustable = totally false. There is really no reason to consider manual control diffusers except to save first cost. And as previously mentioned, you don't save much. And it will be these manually controlled zones that have the most problems.

6. Most VAV diffusers have an acoustical boot on them. This boot provides acoustic isolation from nearby offices or cubicles that does not happen with manual control diffusers. For most major manufacturers of simple VAV floor diffusers a simple rectangular motorized damper modulated the flow from the plenum thru the diffuser. In nearly all cases the damper is on 1 side of an enclosed box with the diffuser grille on top. Happily this geometry creates blockage of sound (both directions) for all but 1 side of the box under the floor. If all of the air inlets are pointed in 1 cardinal direction (north) sound has no direct path in and out of a diffuser form one zone or room to the next. This acoustical isolation has been quantifiably tested to be greater than the construction of all but the most extreme wall construction. So the path of least resistance is thru the partition wall, or thru the ceiling tiles and over the wall. The path thru the diffuser and under the wall back up a diffuser is inconsequential. That is why we always recommend building walls on top of raised floors except plumbing walls, fire walls and demising walls.

In summary, for the most sensible, low cost VAV UFAD system, use VAV in all areas of the building, all the time. Control with PIR and a good BAS system. Any other strategy will harm the return on investment for the building owner.

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