
Steven T. Taylor

Making UFAD Systems Work

BY STEVEN T. TAYLOR, P.E., FELLOW ASHRAE

Underfloor air-distribution (UFAD) systems went from "the next best thing" among HVAC systems in the late 1990s and early 2000s to few and far between after 2010, at least in the San Francisco Bay Area. The reason is simple: they have not worked very well! At least that is the case when using the most common U.S. designs. While the convenience of the underfloor plenum for wiring was a real benefit, and surveys show that occupants perceive much better indoor air quality compared to overhead systems, the hype about improved comfort and energy savings has not been realized for most projects.

Comfort problems, in particular, have been worse than with overhead VAV systems in the author's experience. But the reason may be a result of how UFAD system design changed since it was first introduced in the U.S.

Early Days of UFAD

The first UFAD system in the Bay Area was designed for Gap Inc. in San Bruno, Calif., by an English engineering firm based on design concepts drawn from UFAD systems developed in Europe and Southeast Asia. The design included a system to handle envelope heating and cooling loads that was separate from the interior UFAD systems. The initial perimeter system design used underfloor water-source heat pumps, but for various reasons, including high cost, the final design was a variable air volume change-over (aka, variable volume and temperature, VVT) system with an air-handling unit (AHU) serving each exposure as shown in *Figure 1*. The interior zones were served by separate UFAD AHUs supplying 63°F [17°C] supply air. It took a while to debug and tune, as with any new system, but ultimately the design was a success.

But this was a unique building: it had really only two long uniform exposures (the short ends had other building elements served separately) and it was built into a hill that provided a convenient basement area for air handlers as shown in *Figure 1*. The concept could not be replicated on almost any other building.

Development of the UFT Design

The separate perimeter zone heating and cooling system was a problem: it was expensive and hard to accommodate architecturally, requiring extra shafts at the perimeter or equipment, such as fan-coils or heat pumps, crammed under the floor where they could cause noise problems and were difficult to maintain.

In the early 2000s, the author's firm helped develop alternative designs to reduce cost by combining the interior and perimeter systems into one. The design that became the most popular in California was the underfloor terminal UFAD system shown in *Figure 2*. Underfloor terminals (UFTs) are small fan-coils with variable speed fans and modulating electric or hot water heat. Fan-coils that could fit under the floor (typically 14 in. to 18 in. [355 to 460 mm] high) between the

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FIGURE 1 Gap San Bruno UFAD.

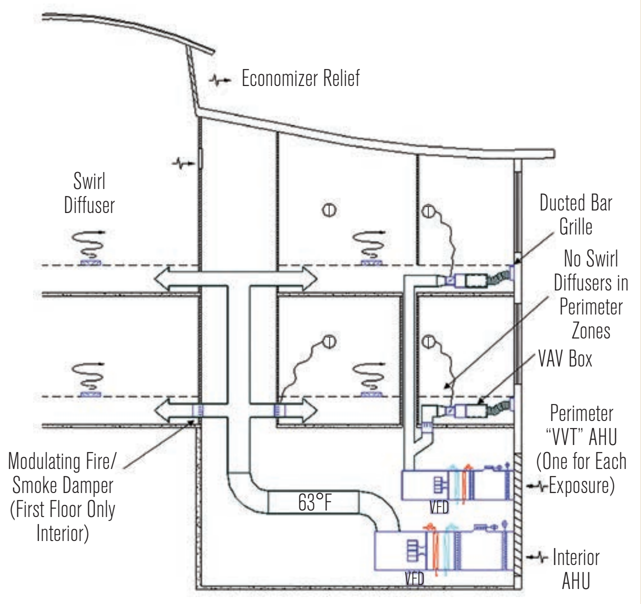


FIGURE 2 Underfloor terminal UFAD.

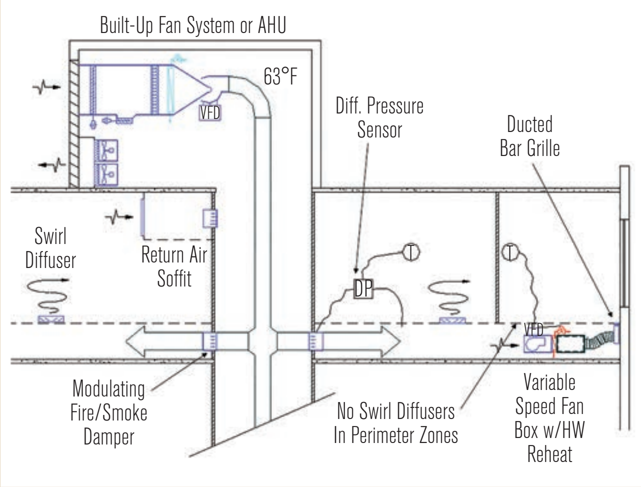
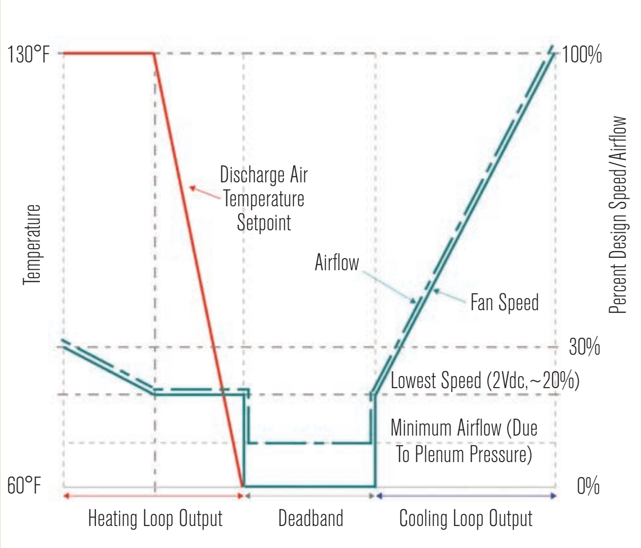


FIGURE 3 UFT control.



pedestals (24 in. [600 mm] on center) did not exist when we first used the system so we used custom fan-coils; now UFTs are standard products available from many manufacturers.

On our projects, UFTs are controlled as shown in *Figure 3*. Initially, we had the UFT fan stay on in the deadband between heating and cooling, but the electronically commutated motors (ECMs) had a minimum speed of 20% (2 vdc to 10 vdc range) and since the fans were direct drive, this often resulted in a much larger percentage of the design flow. This high minimum rate pushed the zone into heating most of the time, causing cold complaints (similar to those caused by high VAV box minimums[1]). So the logic was changed to shut off the fans in the deadband, significantly improving comfort and efficiency. With the fan shut off, the space is still ventilated by leakage through the UFT and the floor due to the pressurized floor. The heating control logic is identical to "Dual Maximum" VAV Reheat logic:[2] the first stage tries to heat the space at the minimum airflow rate; if that is not sufficient, the airflow is increased to 30%, the maximum allowed at the time by ASHRAE/IES Standard 90.1 and California Title 24 Energy Standards. But because the UFT is supplying warm air from the floor at the window, the supply air temperature can be much warmer (e.g., 130°F [55°C]) than an overhead system where stratification can hurt performance.

The supply air rate of cool air from the central AHU to the underfloor plenum was controlled by pressure controllers whose setpoint was reset (typically in the range of 0.01 in. [2.5 Pa] to 0.05 in. [12.5 Pa]) by interior zone space temperature control loops. The low underfloor pressure required with this design minimizes concern with floor leakage that plagues UFAD designs requiring higher pressures.

At the time, we thought the system was ideal: it was reasonably cost efficient, it could be used on almost any building regardless of architectural footprint, and it was energy efficient. The reheat losses were minimal due to the warm central system supply air temperature (63°F [17°C]) and low UFT airflow rates required due to the warm UFT supply air temperatures (130°F [55°C]). But it had a major unanticipated flaw: underfloor supply air temperature degradation (aka, thermal decay). The supply air temperature in the underfloor plenum starts at 63°F [17°C] but by the time supply air crosses the floor from the supply air shafts located in the core out to the UFTs at the perimeter, the air was very warm, 68°F [20°C] and higher, due to heat transfer from the floor served and through the structural slab to the floor below as shown in *Figure 4*.[3] *Figure 5* shows underfloor plenum temperatures for a large project in Sacramento, Calif., our first using UFTs, measured using temporary data loggers placed under the floor. The red squares are the shaft locations and the gray lines are the air-distribution ducts, which had low velocity air outlets every 20 to 30 ft [6 to 9 m]. The temperatures near the injection points that were located near the shafts were close to the 63°F [17°C] AHU supply air temperature, but the temperature quickly decays moving outward from the shafts. On the west side, supply air temperature at UFT inlets was as warm as 72°F (22°C), way too warm to properly cool the offices on that exposure. But if the supply air temperature from the AHU were reduced to compensate, then the interior zones would be overcooled even at zero plenum pressure (no airflow) due to radiation and convection from the cold floor. There was simply no way to satisfy both exterior and perimeter zones at the same time.

FIGURE 4 Heat gain causing supply air temperature degradation.

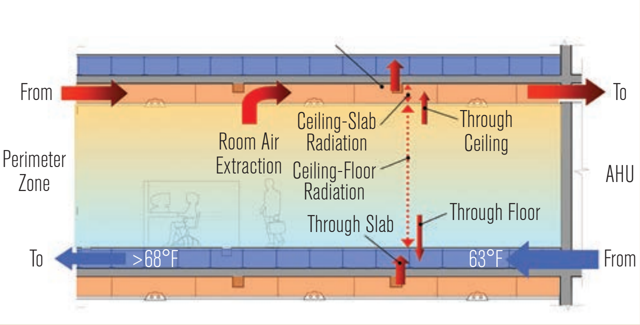
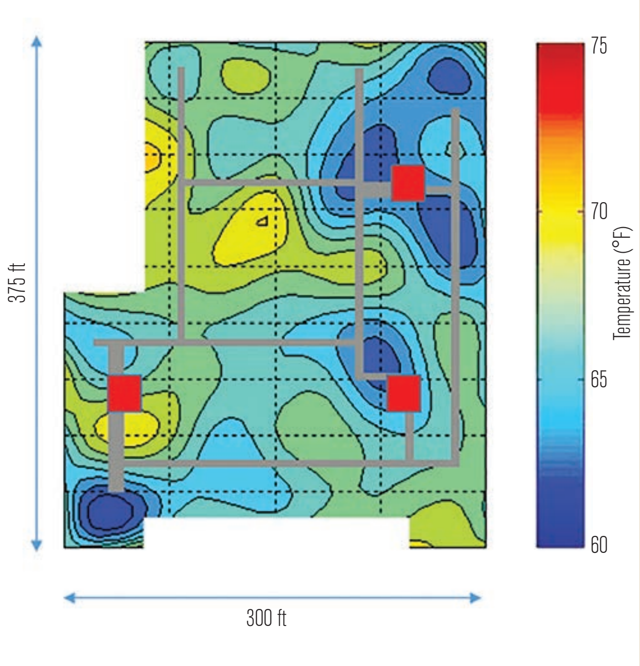


FIGURE 5 Supply air temperature degradation—Capital Area East End Building. (Courtesy of Center for the Built Environment)



Despite the problems seen in our early designs, we did not abandon the UFT concept; instead we tried various kluges to fix it, including:

- More extensive supply air ducts under the floor. Some early designs had almost no ductwork; they were disasters. It soon became apparent that some ductwork is needed to reduce the distance from the point of injection to the UFTs. We at first had the "50 ft rule"—no more than 50 ft from the injection point to the UFT. Better, but not good enough. Soon this morphed into the "40 foot rule," then the "30 foot rule," and then the "20 foot rule." Many designers even went to the "0 foot rule"; they completely ducted the entire perimeter system and converted UFTs to VAV boxes. The perimeter system at that point was simply an overhead VAV system moved under the floor.
- "Rifles" and "shotguns." Initial designs injected air under the floor at relatively low velocities with an airflow spread ("shotgun") to distribute the air evenly and avoid any induction effects from nearby swirl diffusers. But low velocity makes temperature degradation worse. So for exterior zones, we started using higher velocity outlets ("rifles") located directly in line with the UFTs. Because of the Coanda effect from both the structural floor below and raised floor above, the air would rifle with little induction out to the UFT, providing colder inlet air. We included vertically mounted volume dampers at the outlet so we could literally aim the air at the UFT.

These tweaks (and others outlined in the ASHRAE *UFAD Guide*[4]) improved performance, but problems remained. After about our 15th building using the UFT design with less than excellent results, it became clear to us: the Europeans had it right in the first place; the perimeter should be served by separate systems with UFAD only used to condition interior spaces.

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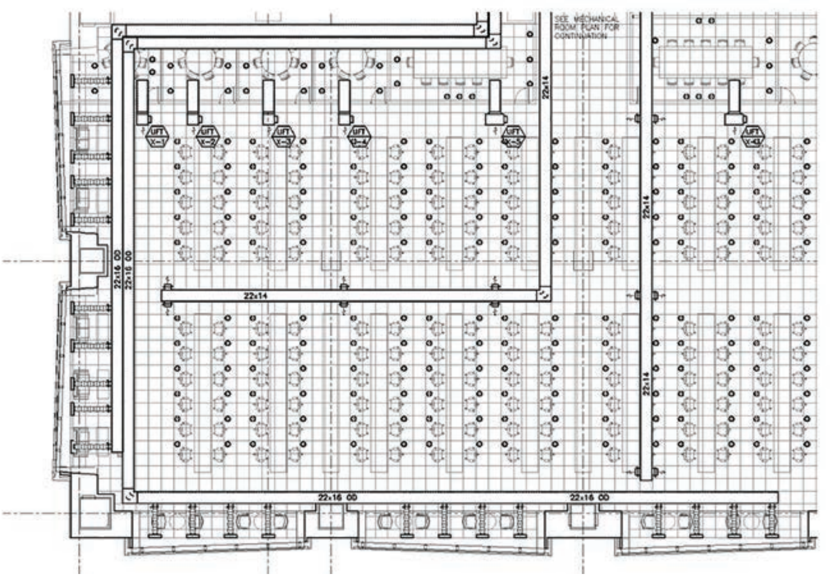
Back to the Drawing Board

The author's firm was recently retained to design mechanical systems for two new projects* for which UFAD was deemed a necessity by the owner to attract high tech tenants. Convinced we needed separate perimeter systems, the task then became how to do so efficiently and cost effectively.

The design we developed works well for our two projects because they have these characteristics:

- Relatively regular rectangular shape (no curves, zig-zag, or slanted exposures); and
- Side (rather than center) cores that allow air handlers to be located on each floor with access to the exterior walls for economizer outdoor air intake and relief.

FIGURE 6 South HVAC floor plan.



The design is summarized as follows:

- Each building exposure is served by a separate AHU, one per exposure. These are ducted to bar grilles in the floor directly under the windows. These AHUs have heating and cooling capability and are designed to condition just the envelope loads.
- Internal loads (lights, people, and equipment) are conditioned by cooling-only AHUs discharging air under the floor with occupant-adjustable swirl diffuser outlets located at each work station—the classic UFAD design.
- Each AHU has its own outdoor air economizer section, but they all draw through a common outdoor air plenum with a single airflow measuring station (AFMS) to measure and control overall outdoor airflow.
- The AHUs are 24 in. [600 mm] wide to match the width of the raised floor tiles and capable of supplying about 3000 cfm [1400 L/s]. The depth (30 in. [760 mm]) could be increased to increase airflow capacity, but the airflow is limited by the size of the supply air ducts, which, in turn, are limited by the pedestal dimension and raised floor height. Access is only required from one short side of the AHUs (optional for the opposite side) and not required on the long sides so the AHUs can be racked side by side, allowing for a very compact mechanical equipment room (MER). The supply fans are upside down plug fans that extend below the floor and discharge into 22 in. [560 mm] wide ducts that just fit between the floor pedestals. The fans are variable speed, either specialty plug fans paired with ECMs (EC fans) or standard plug fans and motors with variable frequency drives. (The design borrowed features from both downflow computer room air handlers and in-row computer room cooling units.) These AHUs are currently semi-custom but very simple and easily manufactured by almost any air handler manufacturer.
- The perimeter AHU ducts are 22 in. [560 mm] × 16 in. [380 mm] OD ducts with slip-&-drive flat seams that lay flat on the floor between the floor pedestals and under the 18 in. [460 mm] raised floor. They are internally lined with 1 in. [25 mm] duct liner to minimize any heat gain to the floor when supplying warm air in heating mode. Interior AHU ducts are 14 in. [355 mm] high and uninsulated; they are raised off the floor 1.5 in. [38 mm] to allow wiring to pass below. Duct size is maintained the same the entire length to reduce pressure drop, compensating for higher than normal initial friction rates.

A floor plan of the air-distribution system for the south half of the building is shown in *Figure 6*. The south MER plan is shown in *Figure 7;* no piping is shown for clarity. *Figure 8* shows side and front elevations of the AHU.† The

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*In association with Foster Partners on one project and ACCO Engineered Systems on the other.

†For humid climates, a return air coil bypass damper could be added below the cooling coil to allow the coil to cool supply air to 53°F [12°C] then blended with return air and supplied at 63°F [17°C].

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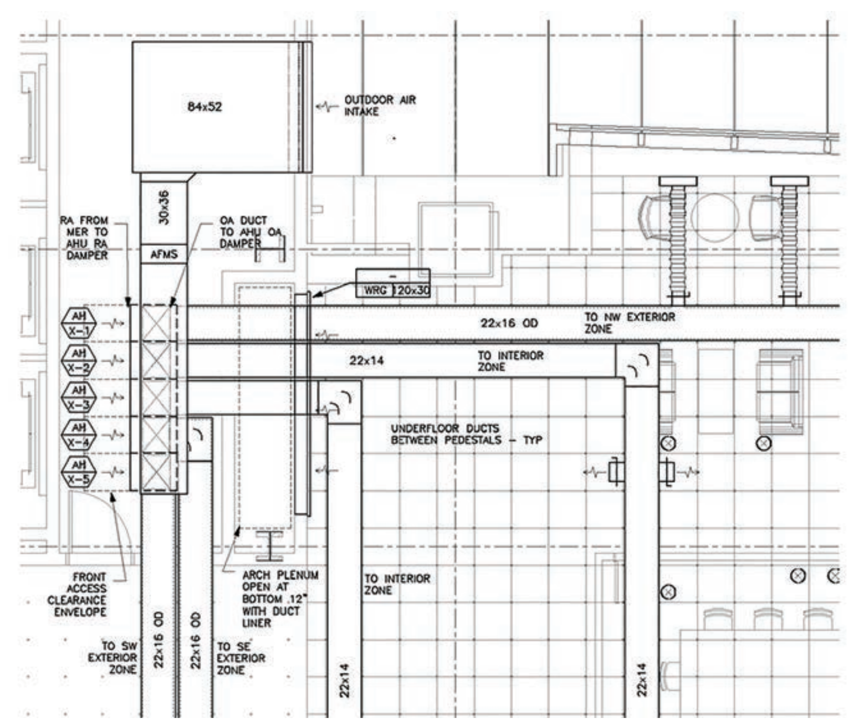
AHUs will be controlled using single zone VAV (SZVAV) logic from pending Guideline 36P;[5] the logic, which balances fan energy with outdoor air economizer energy savings, will be the subject of a future column.

This system has many advantages and should solve issues experienced with other UFAD designs:

- The fully ducted perimeter system substantially eliminates concerns about supply air temperature degradation; envelope cooling loads can be handled without any risk of overcooling the interior.
- All cooling AHUs have outdoor air economizers whose performance is enhanced by the relatively warm 63°F [17°C] supply air temperature, which reduces mechanical cooling operation by more than 2,000 hours per year in this climate compared to overhead systems supplying 55°F [13°C].[II] Hydronic perimeter systems (e.g., chilled beams, radiant slab) might have lower transport energy but would require more mechanical cooling, which makes them less efficient than systems with air economizers in Bay Area climates. This is true even when the chilled water system has a water economizer. Water economizers are not as efficient as air economizers,[6] particularly in this climate.
- There is no simultaneous heating and cooling at all. All systems that have a central AHU serving multiple zones experience some simultaneous heating and cooling. This is certainly true of UFTs (*Figure 3*) and standard overhead VAV systems. But it is also true of dedicated outdoor air systems (DOAS) serving zonal coils if the DOAS AHU has any heating or cooling capability—at some point it will either heat air that is then supplied to a zone that is in cooling mode (and would have benefited from unheated air) or it will cool air that is then supplied to a zone that is in heating mode.
- Because our design has a bank of AHUs serving the floor with common outdoor air and return air paths, outdoor air can be supplied by the interior units in economizer mode while the perimeter AHUs can supply zero outdoor air in heating mode when the weather is cool, most of the year in this climate. Basically the interior cooling loads will effectively heat the minimum ventilation air for less than free –free cooling and free outdoor air preheating are provided at the same time. When outdoor air temperatures are cold enough that the interior AHUs would be overcooled supplying minimum ventilation outdoor air, non-zero minimum damper position setpoints would be maintained on the outdoor air dampers on the perimeter AHUs so they also can supply the outdoor air. They have heating capability so the air can be heated.
- The system has no VAV dampers so there are no associated pressure drop losses. Using an automobile analogy, VAV dampers (and two-way control valves on hydronic systems) act as brakes while fans (and pumps in hydronic systems) act as the motors/accelerators. In a car we avoid stepping on the brake and accelerator pedals at the same time, but typical variable flow air and hydronic systems do it all the time. With the SZVAV design, there are only variable speed accelerators and no brakes so fan energy is minimized.

FIGURE 7 South HVAC mechanical equipment room plan.



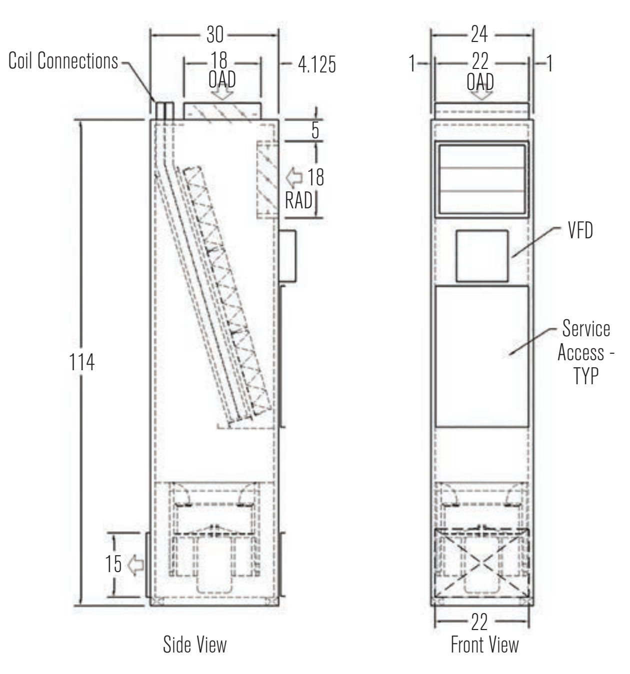
[II] Supplying air this warm without dehumidification is possible in the Bay Area because of the very mild weather. For humid climates, return air coil bypass dampers must be provided to reduce space humidity. This negates the economizer advantage of UFAD systems vs. overhead systems.

- If a perimeter exposure has a very large solar gain such that a 22 in. [560 mm] × 16 in. [380 mm] OD duct would be too small at the typical 63°F [17°C] UFAD supply air temperature, the AHU supply air temperature can be lowered down to as low as 55°F [13°C] during peak load periods. Colder air will not result in discomfort from drafts because it is supplied right at, and upward along, the glass line, not near workstations.
- All coils and all piping are in the MER. No piping is under the raised floor so there is little risk of a leak causing underfloor water damage.
- All maintenance can be done in the MER; there are no dampers, control valves, or terminal units under the raised floor at all. This is a significant advantage over typical UFAD designs, in particular UFTs, which require regular filter maintenance. Devices under the raised floor are often difficult to access, e.g., a desk or filing cabinet must first be moved, then the carpet tiles, and then the floor tiles.
- Enclosed conference rooms can be provided with individual temperature control using cooling-only UFTs supplying sub-plenums created by full height walls or plenum dividers. Examples are shown in *Figure 6*.
- Costs are similar to and can be lower than the UFT design; duct runs are a bit longer but hot water distribution and the UFTs themselves are eliminated.

But, as with all HVAC systems, there are some disadvantages:

- The exterior zone ducts can block access for wiring from the underfloor plenum to perimeter columns and electrical boxes and swirl diffusers cannot be located where the ducts are located. The wiring issue can be mitigated by providing notches on the bottom of the duct at regular intervals to allow wiring to pass under.
- The exterior systems can "fight" with interior systems. While fighting is possible with all systems that have perimeter zones open to interior zones, the "skin" system concept can result in swirl diffusers that are located close to the temperature sensors controlling the perimeter AHUs, typically located on an exterior column. Mild fighting can also occur in perimeter conference rooms also served with UFTs.
- The design cannot be practically applied to all buildings; it applies only to architectural layouts like those on our two projects, i.e., floor-by-floor air handlers and largely rectangular floor plans.

FIGURE 8 AHU elevations. (Courtesy of BASX Solutions)



Conclusions

Our UFAD designs have come full circle, starting with a European concept that worked well, morphing into the UFT concept that seldom worked well, and then back to a design that once again has separate perimeter and interior systems. Note that neither of the buildings using our new design has been built; perhaps I'll write another column a year from now about unexpected problems we encountered.

References

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