OPTIMAL VAV CONTROL OF UFAD SYSTEMS: TIME MODULATION VS FLOW MODULATION

By Matt Bhumbla & Alf Dyck

Variable Air Volume (VAV) Underfloor Air Distribution (UFAD) Systems can be categorized by their air flow modulation strategy: time modulation or flow modulation.

Time modulation systems use time duty cycles of fully open and closed periods to provide VAV airflow in the space. The dampers are typically two-position (on/off) and the controller uses Pulse Width Modulation to cycle the dampers at varying time intervals as the space load conditions change. The goal of time modulation is to achieve constant throw and velocity at all load conditions.

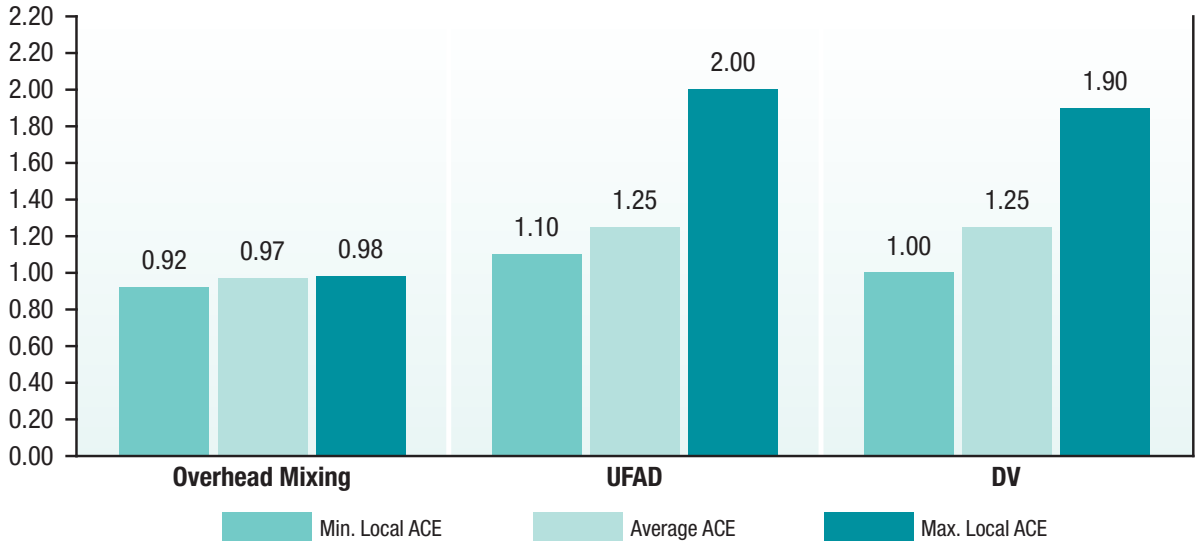
Flow modulation systems modulate the air flow up or down as the space load changes. The goal of flow modulation is to maximize the use of stratification to achieve comfort and improve system efficiency while controlling air flow in response to changing space loads.

To evaluate the two systems, we first need to know the reasons why building owners typically decide to go with UFAD Systems: Indoor Air Quality (IAQ), thermal comfort and energy efficiency.

IAQ in a space can be gauged by its Air Change Effectiveness (ACE) or Ventilation Effectiveness (VE). Figure 1 (Jung & Zeller, 2005) shows the results of a study conducted by researchers at the Rheinisch-Westfalische Technical University of Aachen, Germany, and translated by the Center for the Built Environment (CBE). The diffusers used for UFAD testing were densely spaced and had low throw height, which is typically associated with diffusers used in flow modulation systems. Reported local values of ACE are

UFAD in use at a family foundation's headquarters in Seattle, WA. © NBBJ

Figure 1 - UFAD and DV systems returned significantly greater ACE ratings than the overhead mixing system. The UFAD system used densely spaced, low throw height diffusers typically used with flow modulation systems. However, time modulation and related diffusers will promote mixing in the breathing zone and most likely end up achieving an ACE similar to overhead mixing.



taken at breathing level. UFAD achieved an average ACE of 1.25; this value is much higher than an overhead mixing system and is similar to a displacement ventilation (DV) system.

Since time modulation operates on the principle of either full open or closed, the diffuser throw and velocity will be at maximum whenever there is a call for cooling. The advantages of reduced throw and greater stratification at part load are not realized with this control strategy. At the typically selected design flow of these diffusers, the resultant throw is 6.5 ft (2 m) at 50 fpm (0.25 m/s) terminal velocity. This projects well into the occupied zone, causing unwanted mixing, and most likely generates ACE values that are similar to those of an overhead system (ACE=1).

ASHRAE 62.1 (2013) recommends a vertical throw of less than or equal to 50 fpm (0.25 m/s) at a height of 4.5 ft (1.4 m) above the floor to achieve a Zone Air Distribution Effectiveness (EZ) value of 1.2. This would imply UFAD systems using time modulation may not qualify for 1.2 Zone Air Distribution Effectiveness and would require 17% more fresh air delivered to the space compared to a UFAD system using flow modulation.

The results from another study were shared in an ASHRAE journal article (Webster, Bauman, & Reese, May 2002). This study indicates that the following factors play a prominent role in sizing UFAD systems: floor heat transfer, thermal bypass, supply air temperature and stratification. “Promoting stratification” is identified as the key to minimizing supply airflow requirements, and limiting diffuser throw is described as a key method for increasing stratification.

It should be noted that too much stratification can lead to comfort issues; however, recent research by CBE (Zhang et al.) has expanded the acceptable stratification range. As a result, Addendum A of ASHRAE Comfort Standard 55 now allows up to 7.2°F stratification for a standing person.

While constant mixing and throw are desired characteristics for fully mixed air systems like overhead air distribution, UFAD systems deliver air directly into the occupied space and are therefore designed to thrive on stratification to provide IAQ, thermal comfort and energy efficiency. Unless modified to achieve stratification, time modulation limits the operational efficiency, space comfort and ventilation effectiveness benefits that UFAD systems are expected to offer.

HIGHLIGHTS

+ The goal of time modulation is to achieve constant throw and velocity at all load conditions.
+ The goal of flow modulation is to maximize the use of stratification to achieve comfort and improve system efficiency while controlling air flow in response to changing space loads.
+ Stratification has been identified as a key method of achieving the design goals of a UFAD system.

REFERENCES

- Jung, A., & Zeller, M. (2005). Analysis and Testing of Methods to Determine Indoor Air Quality and Air Change Effectiveness. Original technical paper from Rheinisch-Westfalische Technical University of Aachen, Germany, 1994. English translation by Wolfgang Lukaschek, Center for the Built Environment. Exec. Summary by Fred Bauman, P.E., Center for the Built Environment.
- Webster, T., Bauman, F., & Reese, J. (May 2002). Underfloor Air Distribution: Thermal Stratification. ASHRAE Journal.
- Zhang, H., Huizenga, C., Arens, E.A., & Yu, T. (2005). Modeling Thermal Comfort in Stratified Environments.