Commissioning Raised Floors for UFAD Applications

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Synopsis

The popularity of raised flooring systems appears to be on the rise perhaps, at least in part, due to the need to build "timeless" or flexible facilities to cope with ever changing needs and usage types.

Commissioning has been a leading contributor to the energy and operational performance of a project. For raised or access floors used in an underfloor air distribution (UFAD) application, the commissioning process is of vital importance to the system functionality. However, it is often overlooked since there is fragmented responsibility between parties responsible for it.

This paper outlines the holistic commissioning plan for a raised floor environment used in a UFAD application from pre-design through construction. Key components of that process include:

- Defining the UFAD performance metrics through the use of ASHRAE (American Society of Heating, Refrigeration and Air-Conditioning Engineers) guidelines.
- Commissioning coordination techniques prior to construction.
- Phased testing for UFAD plenum performance characteristics, including air tightness to establish a strong baseline.
- The Commissioning Acceptance Phase including "Prerequisites to Acceptance Procedures", "Verification", "Certificate of Readiness", "Performance Testing", "Documentation", and "Final Acceptance".
- The integration of the commissioning process with modern day tools and techniques such as Computational Fluid Dynamics to validate the performance of a UFAD system.

About the Author

Don Beaty is the Founder/President of DLB Associates, Consulting Engineers, P.C., and is a licensed Professional Engineer in over 40 states. Over the course of the past 30 years, Don's mechanical / electrical / industrial engineering firm has helped construct more than $1 billion dollars worth of mission critical facility. He is a 23 year member of ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) where he founded and is current Chair for technical committee TC 9.9 Mission Critical Facilities, Technology Spaces and Electronic Equipment. Other industry association involvement includes membership in ISA, ASTM, Green Buildings, and IESNA. Don has written over 30 papers / articles in the past 12 months alone on topics ranging from high density cooling to raised floors, cooling infrastructure design, utility optimization, and liquid cooling.

Introduction

Access or raised floor systems have been used on a wide variety of projects ranging from offices to schools to mission critical data centers. In certain applications, the floor cavity between the floor slab construction and the top of the raised floor tile is a relatively short height and is only used to route cabling and miscellaneous infrastructure. However, other applications of raised flooring increase the cavity height and utilize the cavity as an air plenum. This system is often referred to as Under Floor Air Distribution (UFAD).

An Introduction to UFAD Systems

The HVAC air distribution for the majority of commercial building installations is facilitated by sheetmetal ductwork. Predominantly rectangular in cross section, mains ductwork originates with a connection to the HVAC system fan (e.g. inside a Rooftop Unit, Central Station Air Handler). The ductwork is the main artery or trunk for the transporting air to the various spaces.

Branch ductwork is connected to this main trunk and the airflow is balanced such that specific amounts of air are transported in a given branch duct and the mains cross sectional size is typically reduced downstream of the branch ducts to account for the drop in airflow that is being transported.

All of the ductwork routing is typically within a ceiling cavity. The ceiling cavity is defined as the space between the finished ceiling surface (e.g. ceiling tile grid system or sheetrock ceiling) and the underside of the structure of the floor above or the roof. The air is introduced to the occupied space through supply air diffusers mounted in the ceiling and connected to the branch ductwork.

Raised floor systems essentially provide a false floor for the occupied space. A grid is made up of raised floor pedestals mounted to the floor structure (e.g. concrete slab). These pedestals are spaced based on the floor tile size since they support the four corners of each tile. A typical spacing grid is a 2 foot square.

In some cases, the pedestals are tied together with stringers (a secondary support structure that connects the tops of the pedestals). The flooring system is completed with 2 foot square metal floor tiles which are placed on top of the pedestal or pedestal/stringer support system. The height of the pedestals establishes the height of the raised floor cavity.

In UFAD systems, the floor cavity created by the raised floor system replaces conventional ceiling mounted ductwork and supply air diffusers as the means by which air is distributed and introduced to the occupied space. However, air distribution in a floor cavity is not transported in the same rigid manner that it is in a ceiling cavity using ductwork.

Air is introduced into the floor from the system fan of the air handling or rooftop unit. In some cases, this unit may actually be located on top of the raised flooring system with its supply fan directing air movement from the occupied space into the floor cavity. Since the floor cavity is of a continuous volume, the air in the floor cavity is not channeled in any specific direction. Instead, the air is allowed to positively pressurize the entire floor cavity. In other words, the whole floor cavity acts as a distribution plenum.

Air is then introduced into the occupied space at the floor level using perforated floor diffusers. These floor diffusers simply replace a 2 foot square tile and can be controlled via an optional balancing damper. The flexibility of the system stems from the ability to change the location of the floor diffusers to different areas relatively easily compared to overhead ducted systems.

Specifying and Commissioning UFAD Systems

In a similar vein to a suspended ceiling, the raised flooring system and components are typically specified by the Architect. The HVAC system is typically specified by the Engineer. In a traditional overhead ceiling ducted HVAC system, the air distribution is contained within the ductwork and only interfaces with the suspended ceiling at the terminal device locations, such as diffusers.

A UFAD application utilizes the floor plenum space more intimately than ductwork in a suspended ceiling and therefore is impacted directly by the plenum performance and construction. However, critical issues that affect the plenum performance, such as air leakage, are less of the concern for the Architect and may not influence a traditional commissioning process.

A commissioning process for a UFAD system has the same goals as that of any commissioning effort.

- The performance requirements need to be identified, validated and quantified (i.e. develop metrics) prior to construction.
- Coordination and adherence to achieve the performance requirements should be planned before construction and monitored during construction.
- The performance metrics established prior to construction need to be confirmed through measurement.

Since the development of the metrics for a UFAD system is highly dependent on the Engineer but the specification of the system is typically the responsibility of the Architect, there is a need to increase the level of interaction between the two disciplines to ensure a design that meets the overall goals.

Some Background on UFAD's in Mission Critical Data Centers

UFAD systems are very common to the mission critical data center industry, due in no small part to the frequent and prolific change that is experienced in the industry. A common driver for this change is the much shorter refresh rates of computer equipment compared to building cooling systems in general. Information Technology (IT) equipment manufacturers typically work on a product cycle (or equipment replacement cycle) of 2 to 5 years. HVAC systems and components are typically designed to a much longer life cycle (10 to 25 years).

Therefore, it is very common for mission critical facilities to experience multiple changes in the equipment they house throughout the life of the facility. The impact of these changes is difficult to quantify; however, ASHRAE's recent computer equipment trend charts indicate an upward trend in the power consumption of the newer equipment. Consequently, the changes in equipment may result in significant changes in the location, magnitude and density of the resulting heat loads that need to be cooled. With each change, a substantial recommissioning effort may be required.

The movement towards technology compaction in the IT equipment industry is raising the density of the heat loads at a rapid rate. The advent of blade servers is a prime example. In the space of 1 to 3 traditional computer servers, you can fit up to 24 equally powerful blade servers. These new high density loads are not only extremely challenging to cool in their own right, but it also means that any cooling disruption can result in operational meltdown in a matter of minutes, or even seconds in extreme cases. The UFAD system needs to be a lot more precise than it has had to be at any time in the past.

Compounding the problem of high density loads and moving targets that the changing equipment provides is the fact that mission critical applications are typically required to operate 24 hours a day, 7 days a week; therefore, a high level of reliability is paramount. The commissioning of a UFAD system for a mission critical facility requires a much greater emphasis on reliability since the cooling is a vital component in maintaining the availability of the facility to perform its function.

The commissioning and recommissioning processes possibly should describe a more holistic building lifetime commissioning requirement, with goals more geared towards building lifetime objectives rather than being tied to a specific construction activity.

UFAD Performance Metrics

Commissioning has been found to be a leading contributor to the energy and operational performance of any project; for UFAD systems, commissioning is often a necessity. It is not uncommon to observe ten to thirty percent improvement in energy conservation and operational performance through the execution of a holistic commissioning process.

Design Airflow Metrics

There are two main aspects to defining the performance metrics for UFAD systems. The first is the overall metrics associated with achieving the designed operation (i.e. ensuring that the designed airflow at the diffuser locations is achieved).

The parameters that affect the delivery of this airflow are numerous and interdependent. One common one is the height of the raised floor cavity itself but this height only determines the impact of the other parameters such as the plenum contents. Consider the following two scenarios:

- The performance of a 12” high cavity where the plenum space is predominantly dedicated to airflow and contains minimal obstructions.
- The performance of a 24” high cavity where the plenum space is used for airflow and the infrastructure routing for other systems (e.g. cabling) and therefore contains an above average number of obstructions.

It is not a simple task to define which of the two scenarios represent the better probability to attain the air distribution performance metrics and both have to be evaluated individually.

Airtightness Metrics

Another major performance metric that should be defined has to do with the airtightness of the raised floor cavity installation. Variables in the quality of manufactured products can result in excessive leakage rates through the seams in the floor tiles. The type of floor covering that may be placed over the tile also plays a part and can vary in its impact.

However, the airtightness metric can be specified quantitatively. For example, typical criteria would state a maximum value for the leakage rate of the floor tile seams to be 0.75 CFM per linear foot at a static pressure of 0.5” w.g. for bare floor tiles or 0.15 CFM per linear foot for floor tiles that have a carpet tile finish (note: to achieve better airtightness, the seams of the carpet tiles should be staggered so that they do not coincide with the seams of the bare floor tile below).

These metrics are specific to the raised floor installation and the more traditional components of the UFAD system (e.g. air handling units) also require performance metrics. Those have the benefit of being better defined since their use is a lot more commonplace outside of the UFAD world.

Commissioning Coordination Techniques Prior to Construction

During the design phases, we have predominantly been looking at the coordination required between the Architect and the HVAC Engineer with a view to being able to provide sufficient direction to the raised floor system vendor / installer and the HVAC Contractor to achieve the desired UFAD performance. However, in addition to those two disciplines, there are other trades can have a significant impact on the performance of the UFAD system.

These other trades include:

- Fire suppression
- Low voltage special systems such as fire alarm and security
- Plumbing (e.g. piping passing through such as condensate, water, sanitary, & storm)
- Electrical (e.g. cable and conduit including wire management systems)

The impact of these other trades will vary on a per project basis but unless sufficient commissioning coordination takes place, the risk of the impact significantly affecting the overall UFAD performance increases.

Coordinated Shop Drawing Process

A technique that can assist in the coordination of the multiple trades that may need to interface with the raised flooring system is the use of the coordinated shop drawing process. The coordinated shop drawing documents the physical location of the components of every trade within the raised floor cavity and then assesses the impact of those components on the UFAD system.

A typical process would be initiated by the raised flooring vendor / installer who would produce a shop drawing of the raised floor area, including the location of all of the raised floor pedestals. This drawing would then be passed onto and augmented by each of the trades that interface with the raised floor.

Each contractor that interfaces with the raised floor would be required to markup as accurately as possible, the routing of their work before passing the shop drawing onto the next contractor. To enhance the clarity of the drawing further, it is recommended that an enlarged scale be used (e.g. 3/8" = 1'-0").

The final shop drawing should include:

- Composite Routing Drawings showing the location and scaled routing of all trades
- Composite Plenum Penetration Drawings identifying the scaled location of every penetration
- Sections (enough scaled, composite sections to clearly indicate the vertical space issues & coordination)

This enlarged scale plan is used in coordination meetings with the contractors and design team to discuss any potential conflicts and design impact of the installation shown prior to the commencement of any raised floor construction including items that may not have physical conflict, but may be a source of airflow turbulence or an area with a larger amount of penetrations that need to be addressed to maintain plenum integrity.

The use of this coordinated shop drawing process can also allocate responsibility for the plenum integrity to the raised floor contractor. By being the originator of the drawing and also participating in all of the coordination meetings, the raised floor installer can be primarily responsible for all of the penetrations and installation of subsequent accessories to minimize air leakage. It is advantageous for the firestopping / sealant contractor to also be present to understand his scope of work and scheduling.

The resulting coordinated shop drawing can then be used as a living document throughout the construction process. Prior to the construction commencement, the layout of the various trades' components can be transposed onto the actual floor slab so that any previously unknown conflicts or constraints can be identified and resolved. It is much easier to address any issues at this stage.

The floor markings need to be neat, accurate, and color coordinated. Once all trades are marked out and all conflicts / coordination issues resolved, there should be signoff by all participants and the floor extents should be photo documented as well.

As a part of the commissioning process, any marked changes on the coordinated shop drawing should be noted not just for asbuilt information, but also to update the Basis of Design and any other metrics that might have changed.

A similar coordinated shop drawing process can be applied to any instance where there are multiple trades having to collocate their infrastructure in confined spaces (e.g. mechanical / electrical equipment rooms, ceiling cavities, etc.).

Phased Testing for UFAD Plenum Performance Characteristics

Some of the attributes of a raised floor installation that impact HVAC performance and success include:

- Air leakage through the raised floor plenum (i.e. air tightness of the floor cavity)
- Air turbulence due to congestion within the raised floor plenum
- Coordination of the many potential elements and trades that can co-exist in the raised floor plenum

Through the coordinated shop drawing process, the second and third items on the list have been proactively dealt with and their impact can be addressed accordingly prior to construction. However, the first item on the list requires addressing during both design and construction for compliance to the previously established metrics.

The testing of the air tightness of a floor cavity is not a well documented process. Even in the air balancing of a traditional overhead system, although recognized as a critical activity often involving a third party expert and acceptance signoffs, the process is by no means an exact one and often consists of trial and error approaches.

However, by comparison the air balancing effort of a ducted system is a far less challenging task than that of a UFAD system. Some reasons include:

- The interior of a duct is unobstructed, smooth and predominantly promotes a single path of airflow. The interior of a raised floor plenum is far from unobstructed (e.g. pedestals, columns, cabling, piping), has many disruptions and promoted pressurization of a volume with airflow in multiple directions.
- The quantity and linear footage of seams in raised floor system (and therefore the risk of air leakage) is magnitudes greater since it includes the perimeter of every floor tile.

- The number of penetrations in a raised floor plenum (e.g. cable openings in tiles) has a major impact on performance and is a condition not found in ductwork systems.

Adapting the Fan Pressurization (Blower Door) Test for UFAD Applications

A method of testing the air tightness of the raised floor system is to use an adaptation of the method used to test the infiltration or exfiltration of a building envelope. This method is referred to as the Fan Pressurization Test in larger, commercial applications or the Blower Door Test in smaller, residential applications.

The essence of the test is to pressurize and de-pressurize a volume under controlled conditions with the use of HVAC air handling equipment (i.e. a fan assembly). This equipment may be portable and brought to the site for this specific testing process or the building's own HVAC equipment could be used to perform the test if the controls and measurement can be incorporated.

The process involves either blowing air into a building envelope (for measuring exfiltration) or blowing air out of a building envelope (for measuring infiltration). The idea is to raise or lower the internal building pressure above or below the outdoor atmospheric pressure by a set amount. The actual pressure differential to be used will vary depending on the prevailing outdoor conditions.

The airflow required to induce that pressure differential is then recorded and the infiltration or exfiltration at a set pressure level (typically 0.2" w.g.) can then be calculated and is expressed in terms of volumetric air changes per hour and that value is then compared to industry metrics for what constitutes a tight or loose building for a given type and size of application.

Alternatively, another metric that can be calculated is the effective leakage area (ELA). This is defined as the area of a penetration or opening that results in a constant airflow rate of discharge from an envelope for a given pressure differential. Since there are differing requirements for the leakage rate from a building envelope compared to the raised floor plenum, the leakage rate values that are deemed acceptable will also differ.

To adapt the fan pressurization test process for a raised floor system, we need to change a number of parameters.

To accurately simulate the operational conditions, we would blow air into the raised floor plenum and increase the pressure within the plenum space and measure the airflow required to do so. The majority of exfiltration will occur based on the air tightness of the floor cavity.

The pressure differential should be measured against the room static pressure instead of outdoor atmospheric pressure since the majority of leakage would occur internally to the room volume rather than externally through the building envelope.

When fan pressurization tests are carried out on building envelopes, it is good practice to perform multiple tests to obtain a series of pressure differentials. This normalizes the results and mitigates the effects that variable outdoor weather conditions (e.g. temperature, wind velocity, etc.) may have had. However, for a raised floor air tightness test, multiple tests are not as critical since the environment is more controlled to begin with. However, more than one is recommended for confirmation and verification purposes.

More often than not, the HVAC equipment that is used to supply air to the raised floor plenum provides us with the perfect test apparatus to perform the fan pressurization test so no portable equipment is required. Good practice if using this method would be to ensure all filters are swapped out before and after the test has been run to avoid dust and debris that may remain in the floor plenum from being circulated in the units.

More detailed information on the actual testing methodology can be found in ASTM Standard E779-03 (ASTM 2003) and information on Infiltration and Exfiltration calculations can be found in ASHRAE Fundamentals Handbook (2001), Chapters 14 and 26.

Performance Testing Phases

Phase 1 - No Openings or Penetrations

In order to establish a solid foundation from which to measure performance against the previously established metrics, this first phase is strictly a test of the air tightness of the raised floor installations. As such, it should ideally be carried out prior to any openings or penetrations being made in the raised floor system.

If this is not possible (i.e. penetrations have already been made) then a simple remedy would be to replace the floor tiles with the penetrations or perforated diffuser tiles with solid floor tiles or, not as ideal but still somewhat effective, to ensure that the openings were sealed as tightly as possible prior to Phase 1 testing.

Then using the modified fan pressurization test described earlier in this section, a great documented baseline can be obtained and defects can be more easily resolved prior to the installation of equipment and furniture.

Phase 2 – Air Delivery of the UFAD System

A UFAD system typically consists of one or more air handling units supplying air to a raised floor plenum and then the air being delivered back to the room via perforated floor diffusers. The designed location of these diffusers is such that a specific quantity of air is required to be delivered at that specific location. Phase 2 testing is to determine whether that design requirement is being achieved by the installation.

Additional testing can be done at this stage including the impact of changing the quantity and / or location of the raised floor diffusers or in the case of a data center, where the floor plenum typically has more than a single air handling unit supplying air to it, "what if" types of failure analysis can be performed to assess whether the correct level of redundancy has been attained.

Phase 3 – Actual Operating Conditions

This final testing phase is the closest phase to the actual operating conditions and takes place after all equipment and furniture within the space is installed. Depending on the specific application, the equipment or furniture impact on the UFAD system may range from minimal for school environments (i.e. all furniture above the raised floor and no additional penetrations) to moderate for office environments (some penetrations for cabling to computer equipment) to major for data centers (multiple larger cable penetrations, large quantity of underfloor infrastructure, heavier equipment support pedestals below floor, etc.).

The testing in this phase will allow the understanding of the true impact of the penetrations on a design condition and the information may result in a design change to react to a situation that was previously undiscovered.

This phase should also include an accurate asbuilt document building on the foundation of the coordinated shop drawing with all raised floor equipment, infrastructure, penetrations and terminal devices located.

Integrating Commissioning and Computational Fluid Dynamics for UFAD Systems

With the large number of interdependent parameters and variables, the ability to predict the response of a UFAD system to change is a challenging task. In addition to putting an engineered solution in place, intuition and experience can be valuable in predicting the impact of changes to the heat load in response to an IT equipment product cycle update. An alternate technique that is gaining in popularity is to leverage the use of Computational Fluid Dynamics (CFD) software modeling.

An Overview of CFD

CFD software was predominantly used in the nuclear, aerospace and military industries in the 1970's and 1980's. Only the fastest computers available at the time could perform the complex calculations that the expensive software required and so the solution's applicability was limited. However, with the advances the technology industry has made over the last several years, more and more commercial applications are being realized.

CFD modeling basically virtualizes the thermal conditions of an environment. The physical space along with all of the HVAC system components needs to be input digitally into the software and the thermal and material properties for each component must also be described.

Once all of the input is recorded, simulation of the thermal conditions takes place and is iteratively calculated until a convergence or equilibrium is reached. Common outputs include: a graphical representation of the temperature, and pressure and velocity contours of the physical space which can be studied and analyzed.

Combining CFD with Commissioning

During the phased commissioning process of a UFAD system, a parallel approach would be to model the installation using CFD software. The phases described earlier would then be augmented as follows:

Phase 1 - No Openings or Penetrations

During this phase, or even earlier, the physical dimensions of the UFAD environment could be input into the CFD software. Should changes occur during the construction, then those would need to be reflected in the model as well. The fan pressurization test at this stage may yield results that would need to be incorporated as variables into the model. For example, if the leakage rate is calculated, that could be a variable introduced into the model.

Phase 2 – Air Delivery of the UFAD System

This phase would allow for the CFD model accuracy to be determined. The model can be continually adjusted to allow for the airflow readings in the model to closely reflect the actual airflow readings measured during the commissioning process testing. However, the true test of the model's accuracy will be the accuracy of the output when the changes are made to the actual field conditions.

For example, relocating or changing the quantity of the floor diffusers or shutting down one of the air handling units. By performing this test actually and also virtually, a level of comfort can be attained with the accuracy of the CFD model and if that accuracy is within a pre-determined tolerance, then the result is a reasonably accurate virtual UFAD system.

Phase 3 – Actual Operating Conditions

This phase would serve as a further level of accuracy for the model to represent the asbuilt conditions and it is important that all penetrations be integrated into the model as accurately as possible.

Once the virtualized UFAD system is complete, it becomes an invaluable tool to predict the impact of future changes without disrupting the existing operation. Any changes made to the UFAD system in the future can now be planned for in a much more proactive manner. The CFD model allows for numerous "what if" scenarios to be modeled and optimized prior to implementation.

Conclusions

UFAD systems are becoming more commonplace for a wide variety of applications. Since there is a fragmentation of responsibility within the design and construction team, the commissioning process for this relatively new system takes on heightened importance in delivering the desired results. Techniques such as the coordinated shop drawing increases the communication between the various trades and disciplines involved and, thereby, allows a forum to resolve potential conflicts and issues before they have a chance to escalate.

A phased approach to the commissioning of the UFAD system can allow for a more structured approach to ensuring that the design operation goals are met. The void in documentation of commissioning techniques for UFAD systems requires the adaptation of known methods from other fields such as the fan pressurization test.

Applications such as mission critical facilities require an increased level of reliability and the cooling systems represent a vital part of the facility's ability to operate continuously. This further expands the scope of the commissioning process to include the reliability aspect. The mismatch of IT equipment product cycles and building life cycles expand the scope further and may require the integration of CFD technologies to truly commission a UFAD system and allow for true commissioning over the lifetime of the facility.