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UNDERFLOOR AIR DISTRIBUTION

AN EXPERIMENTAL COMPARISON OF AIR DIFFUSION PERFORMANCE BETWEEN UNDERFLOOR AIR DISTRIBUTION AND CONVENTIONAL OVERHEAD AIR DISTRIBUTION SYSTEMS

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EXECUTIVE SUMMARY

A major paradigm of the underfloor air distribution (UFAD) system is that its air distribution characteristics are different than in conventional overhead air distribution (CAD) systems. However, significant thermal gradients have not been observed in several installed UFAD systems; rather the systems appear to perform similarly to CAD systems. Therefore, the UFAD Task Force of the National Center of Energy Management and Building Technology (NCEMBT) recommended that the initial experiments for this task compare the UFAD and CAD system configurations, and specifically determine if the air temperature and velocity gradients are significantly different. The comparison was made with both systems having been designed with an air distribution performance index (ADPI) of greater than 80%.

This project covered the laboratory investigation phase of Task 2 where the performance and cost-effectiveness of UFAD and conventional air distribution (CAD) systems were compared. To perform the testing, it was necessary to modify and upgrade the current UNLV Building Technologies Laboratory (BTLab) to obtain experimental data related to energy, performance and comfort issues associated with CAD and UFAD systems. The results of laboratory development, testing and qualification revealed that:

- Conditions maintained in the BTLab were on target, with low enough variation to allow consistent, repeatable testing at the planned input parameters;
- The measured data were replicable and reliable;
- The BTLab was qualified to meet the design criteria, and is a unique, state-of-the-art, automated test room for measurement of quality, efficiency, and effectiveness of different heating, ventilating, and air conditioning systems.

The results of laboratory designed experiments on UFAD and CAD systems revealed that for systems that are similar to the laboratory set-up:

- The ADPI values of the UFAD system in half and zero load tests were about 55% to 65%, much lower than test goal of 80% or higher for a properly functioning system. Thus a detailed comparison of temperature and velocity distributions between CAD and UFAD systems with ADPI of 80% or higher at half and zero load conditions was not possible. The full load tests of UFAD systems achieved ADPI values higher than 80%, and a comparison was made.
- Statistically, there is a significant difference in air velocity and temperature distribution in interior office zones between properly functioning CAD and UFAD systems. The overall air temperature and velocity conditions throughout the occupied zone in CAD systems have less variation than that in UFAD systems.
- UFAD systems need 35% to 38% more airflow rates than CAD systems to achieve the same average occupied zone temperature of 75°F when the supply diffuser air temperatures are set at the industry standard, i.e., 55°F for CAD systems and 65°F for UFAD systems.
- For the UFAD systems for this specific room with no carpet or other floor covering on the raised floor tiles and where halogen flood lights were used, 32% of the lighting load and 15 to 30% of the floor heater load is transferred to the underfloor plenum, while 36% of the lighting load and 70 to 85% of the floor heater load account for the room load. The remaining 32% of the lighting load goes directly into the ceiling plenum.

Based on the ADPI test results, we conclude:

- The null hypothesis that "There are no significant differences in air velocity and thermal distribution in interior office zones between CAD and UFAD systems that are designed to perform at an ADPI greater than 80%" is rejected for both full and partial load conditions.
- For UFAD systems, based solely on ADPI results, the indoor environment is thermally not acceptable under partial load conditions (ADPI lower than 80%) but thermally acceptable (ADPI higher than 80%) under full load conditions, while it is thermally acceptable for both full and partial load conditions in CAD systems.
- Statistically there are significant differences in air velocity and thermal distribution in interior office zones between CAD and UFAD systems that are designed to perform at an ADPI greater than 80%. However the vertical temperature gradients in both CAD and UFAD systems are below the sensible threshold of most occupants, so from a thermal sensation perspective, they have no significant differences.
- When subjected to high plenum subfloor or slab temperatures and/or significant plenum air leakage, UFAD systems may consume more energy than CAD systems to achieve the same average occupied zone temperature of 75 °F with the supply diffuser air temperatures set at the industry standard, i.e., 55 °F for CAD systems and 65 °F for UFAD systems, due to increased supply airflow rates and cooling requirements to keep plenum supply air temperatures significantly below 65 °F.
- For UFAD systems, load calculations need to consider both the room load and the UFAD plenum load. The plenum load may be thought of as similar to duct loss heat load in a CAD system, but these experiments show significant load characteristic differences. Among those are the higher transfer of heat load (both lighting and floor) from the room to the plenum through the floor, the transfer of heat to the plenum from the subfloor, and the possibility for significant variations in plenum air temperature and thus higher variation in diffuser discharge air temperature when compared to CAD systems.

We recommend additional research for UFAD systems, on:

- Reduction of temperature variations in the underfloor plenum.
- Effects of carpet on heat transfer, supply temperature, airflow rate, ADPI values and thermal comfort.
- Effects of occupancy, office cubicle set-up and equipment on ADPI values and thermal comfort.
- Effects of diffuser locations and numbers on ADPI values and thermal comfort.
- Effects of supply air temperature on ADPI and thermal comfort.
- Effects of a combination of parameters (diffuser location and numbers, supply air temperature and load conditions with carpet and office configuration) on ADPI values and thermal comfort.
- A protocol for field measurement methods and field data collection for UFAD systems.

1. PROJECT OBJECTIVE

The specific objectives for Task 2 were to:

- Investigate HVAC design, comfort, and energy issues related to UFAD systems;
- Conduct a series of interactive seminars in conjunction with ASHRAE chapters, to collect current information on the level of UFAD knowledge in the design community;
- Conduct a preliminary field study of existing UFAD systems in commercial buildings to characterize existing installed UFAD systems, identify areas that may require additional laboratory research, and generate information to develop protocols for future field testing of UFAD systems;
- Modify and upgrade the current test facility so that in-depth testing can be conducted to obtain laboratory data related to energy, performance and comfort issues associated with UFAD systems;
- Conduct in-depth laboratory tests to obtain data and answer questions associated with energy, performance and comfort issues related to UFAD systems, and develop test protocols that can be used in future field tests in commercial buildings with UFAD systems; and
- Develop information for future development of design tools that can be used to compare UFAD and CAD system applications.

Three different organizations were contracted to complete these objectives. The Building Diagnostics Research Institute (BDRI) completed objective 2. The principal investigator/presenter was James Woods, Ph.D., P.E. This subtask is complete, and a final report (NCEMBT-040815) has been published. GARD Analytics completed objective 3. The principal investigator was Roger Hedrick. The University of Nevada, Las Vegas (UNLV) completed objectives 4 and 5. The principal investigator is Liangcai (Tom) Tan, Ph.D. All three organizations contributed toward objectives 1 and 6. This report details the UNLV contribution toward the objectives.

2. BACKGROUND

Modern UFAD systems have long been used in Europe and are rapidly gaining acceptance in the United States. In principle, UFAD systems can reduce or even eliminate overhead plenum spaces and sheet metal ducts that make up conventional ceiling air distribution systems. By applying the principle to actual building construction, suppositions were made of reduced construction costs and shortened required deck-to-deck heights in high-rise buildings. However, before such gains can be realized, a number of design issues associated with UFAD systems that have not been fully investigated, need to be resolved. These include:

- Controlling air temperature and humidity in large open under-floor plenums,
- Controlling distributed airflow in large open under-floor plenums,
- Controlling air mixing in occupied spaces served by under-floor plenums,
- Minimizing the presence of moisture in under-floor plenums to prevent fungal (mold) contamination, and
- Controlling the propagation of sound in under-floor plenums to prevent a degeneration of speech privacy in occupied spaces.

The entire report can be accessed via the following link:

http://www.ncembt.org/portal/Portals/0/downloads/Tan%20L_Underfloor%20Air%20Distribution_NCEMBT-080801.pdf