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## ANALYSIS AND TESTING OF METHODS TO DETERMINE INDOOR AIR QUALITY AND AIR CHANGE EFFECTIVENESS

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*The following summary provided by CBE summarizes the test methods and findings from this paper. A translation of the entire paper is available from the CBE publications web page at:*

*<http://www.cbe.berkeley.edu/research/publications.htm>*

### EXECUTIVE SUMMARY

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#### ACKNOWLEDGMENTS

The following paper is a translation of “Analyse und Erprobung von Verfahren zur Ermittlung der Raumluftqualität,” authored by Dipl.-Ing. Andreas Jung and Prof. Dr.-Ing M. Zeller at the “Lehrstuhl für Wärmeübertragung und Klimatechnik Rheinisch-Westfälische Technische Hochschule Aachen, Lehrgebiet Klimatechnik.” The German manuscript, completed in 1994, was originally provided to CBE in August 2005 by Richard Craig of Green Building Solutions, LLC, Denver, North Carolina. Many thanks to Richard for making this valuable information available to us. We also want to express our sincere appreciation to Dietmar Goericke of FLT (Forschungsvereinigung für Luft- und Trocknungstechnik) e.V., the sponsor of the research study, and Prof. Manfred Zeller, one of the original authors, for both agreeing to allow the public dissemination of the translated paper. The paper was primarily translated by Wolfgang Lukaschek, formerly a Research Specialist with CBE, with assistance from Lars Junghans, visiting scholar at CBE. CBE has compiled this translation with care and to the best of our abilities, but cannot warrant that the information in the publication is free of errors. We are pleased to make this report available to the U.S. building industry and other interested parties in hopes that it will improve our understanding of the ventilation performance of underfloor air distribution (UFAD) and displacement ventilation (DV) systems.

#### SUMMARY AND DISCUSSION

In this paper, the authors report on a detailed laboratory study using tracer gas methods to measure and compare the air change effectiveness of four different air distribution systems: (1) overhead mixing with twist outlets, (2) overhead mixing with slot diffusers, (3) UFAD with swirl (twist) floor diffusers, and (4) DV with low side-wall diffusers. The authors devote a significant amount of time and effort (Sections 2-4) describing their theoretical and experimental considerations in the development of their

final test methodology for measuring “age of air.” After evaluating the reliability of three different tracer gas methods (pulse, step-down, and step-up), they decided on a cyclic sequence of step-up and step-down for their measurement strategy.

The experiments were conducted in a test room with dimensions 4m x 6m x 2.8m high. Realistic heat loads in the room were modeled with heated manikins, computers and monitors, a printer, and overhead lighting. Age of air measurements were made at multiple points, including at the nose and 0.3 m in front of both sitting and standing manikins. This allowed the determination and comparison of local air change effectiveness both within the buoyancy-driven plume created by the manikin and a short distance outside this thermal boundary layer. Two series of experiments were carried out for each air distribution system configuration.

Three different air change rates were tested (2.5, 5, and 8 per hour), representing total airflow rates of 0.38, 0.77, and 1.22 cfm/ft<sup>2</sup>. During all tests the total internal load was held constant at 20 W/m<sup>2</sup> (1.9 W/ft<sup>2</sup>).

Three different heat load levels were tested (20, 40, and 65 W/m<sup>2</sup>), or (1.9, 3.7, and 6.0 W/ft<sup>2</sup>). Air change rates were adjusted to maintain a constant temperature difference between return and supply air temperature of about 8.5K (15°F).

**OVERHEAD SYSTEMS.** For both overhead mixing systems, as expected, the results indicate average (global) air change effectiveness (ACE) values close to one (0.96 – 0.98). Local ACEs at the nose of either the seated or standing manikins were also in this same range (0.93 – 0.97), demonstrating the relatively well-mixed conditions throughout the room for the test conditions reported. Due to the close proximity of the return grilles (air was exhausted from the room through the ceiling light fixtures) to the supply diffusers, some short-circuiting was measured at these locations. The turbulent forced flow outlet conditions and resulting room air diffusion for both overhead systems were strong enough to destroy the thermal plumes around the manikins, as there was no difference in ACE at the nose or 0.3 m in front of the manikins.

**UNDERFLOOR AIR DISTRIBUTION (UFAD) SYSTEM.** Of particular interest are the results for the floor twist (swirl) diffusers, or UFAD system. Previously, to our knowledge, there has not been reliable UFAD ventilation performance data of the quality demonstrated in this study available to the U.S. building industry at large. Significantly improved ACE values were measured at all points within the occupied zone (up to 1.7 m high). For the 100% outside air conditions of these tests, local ACE ranged from 1.2 – 2.0 with average ACE values of 1.2-1.3. Some of the local ACE values for the UFAD system were even higher than the corresponding local ACE values for the DV system, a surprising finding. The strong influence of the thermal boundary layer around the manikins to draw fresh air from lower elevations in the room up to the breathing level was clearly demonstrated. For the design case (highest load and highest airflow), the local ACE at the nose of all manikins was noticeably higher than the ACE 0.3 m in front of the manikins. Even at points within the occupied zone that had the lowest ACE values for the UFAD tests, these were still 15% higher than the highest recorded local ACE values for the overhead mixing systems.

Upon close inspection of these UFAD system results, some additional comments are warranted. First, unlike typical UFAD installations in the U.S. today that use either swirl diffusers (with a nominal airflow rate of 80-100 cfm) or VAV diffusers (with an airflow rate of up to 150 cfm), in this experiment, each swirl diffuser delivered approximately 20 cfm. The much smaller size of these diffusers resulted in a relatively larger number of diffusers distributed evenly across the floor of the test room. The vertical throw height of these diffusers was only about 1.1 m (3.6 ft), a value that is lower than typical throw heights (1.2-1.8 m [4-6 ft]) for most swirl diffusers being installed today in the U.S. The lower throw will tend to reduce the amount of mixing in the room, thereby improving air change effectiveness. It is also evident from this rather dense diffuser layout that just about any point in the test room is quite close to a nearby diffuser. In fact, it is this distribution of supply diffusers across the floor

that proves to be an advantage for UFAD compared to DV, which has its supply outlets located along the base of one end wall of the test room.

A second observation can be made regarding the configuration of the internal heat loads in the room. At the lowest load level of  $20 \text{ W/m}^2$ , all loads are modeled using realistic heat sources (e.g., manikins, computers, printers, etc.), resembling large point sources that produce thermal plumes. However, to achieve the higher load levels of  $40$  and  $65 \text{ W/m}^2$ , a distributed heat source was spread across the floor, producing a more laminar upward flow, and thus changing the make-up (ratio of point to laminar heat sources) of the load configuration in the room. The authors acknowledge that by adding heat at floor height, an improvement in air change effectiveness was obtained. Future research is needed to improve our understanding of how different heat load arrangements impact thermal and ventilation performance of both UFAD and DV systems.

While the test conditions for UFAD in this study do not exactly match those commonly encountered in U.S. installations, the results do provide important guidance on design and operating strategies that may improve ventilation performance of UFAD systems. These findings suggest that if load conditions allow it, there may be ventilation benefits in using a larger number of diffusers, diffusers that deliver air with less mixing (lower throw height), or both. Given these encouraging results for air change effectiveness of UFAD systems, it is important that future research investigate more typical UFAD system configurations, including standard floor diffuser size and spacing, as well as variations in heat load configurations.

**DISPLACEMENT VENTILATION SYSTEM.** Due to the low inlet velocities of DV systems, their operation is primarily driven by the thermal plumes and resulting room air stratification generated by the heat load configuration in the room. Similar to results for the UFAD system, significantly improved ACE values were measured at most points within the occupied zone (up to 1.7 m high). For the 100% outside air conditions of these tests, local ACE ranged from 1.2 – 1.9 in the breathing zones (at the noses of all manikins) with average ACE values of 1.2-1.3. In addition, the strong influence of the thermal boundary layer around the manikins to draw fresh air from lower elevations in the room up to the breathing level was again clearly shown. ACE measurements and smoke tests demonstrated that the stratification height (the characteristic horizontal interface separating the lower and upper zones for plume-driven flows) was consistently between 1–1.4 m (3.1–4.5 ft) for all test conditions of this study. The DV system did produce higher local ACE values and gradients compared to UFAD at some locations (maximum of 3.7), but these were located closer to the floor at a height of 0.6 m (2 ft). Also in contrast to UFAD, local ACE values in DV systems demonstrate a higher sensitivity to heat load configuration, cold temperature sources (e.g., cold perimeter window), and local disturbances (e.g., computer fans, breathing).

In conclusion, with proper arrangement of the room heat loads and well-insulated walls (no cold surfaces), no significant differences in terms of local and global air change effectiveness values were measured between DV and UFAD systems.

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