Editorial for HVAC&R Research, 13(6),2007

Computer simulations and experimental measurements of air distributions in buildings: past, present, and future

Qingyan Chen, Ph.D.
Fellow ASHRAE*

In order to design a comfortable, healthy, sustainable, and safe building, it is important to know the distributions of air velocity, air temperature, relative humidity, the temperature of the surroundings, and concentrations of airborne gaseous, particulate, and liquid droplet contaminants. (hereafter referred as air distribution) in the building. Due to rapid development in computer memory and speed, and the advance in computer models, it is becoming popular to perform computer simulations to calculate air distribution in buildings. The most advanced computer models used today for air distribution are Computational Fluid Dynamics (CFD). CFD solves Navier-Stoke equations for flow and conservation transport equations for energy and species. CFD gives detailed information of three-dimensional air distributions. The results can often been presented as movies and animations. It is very exciting to visualize the CFD results for a building before it is built and to use CFD to provide different design alternatives. Typically, to calculate the air distribution in a large indoor space using CFD takes a few hours on a PC, which seems very computationally intensive for most designers who do not have a computer cluster. Thus, although it is powerful, the applications of CFD to building design have been mainly limited to single spaces (zones) or several spaces connected by large openings.

In parallel, researchers have been working on simplified models for the calculations of air distribution in buildings. Zonal models are simplified models that use only a few nodes in a space to determine the most critical information regarding air distribution. The critical information could be the vertical gradient of air temperature and the non-uniform distributions of airborne contaminants. Zonal models are also based on solid physics, such as conservation equations for mass, energy, species, etc. However, more approximations are used so that a computer can easily solve the equations.

If a building contains dozens of rooms (zones), the computing time of zonal models can be very long if the models are applied to the entire building. Hence, one would use multizone models that have only one value for each parameter in a zone. For example, each room would only have one uniform air temperature and one uniform carbon dioxide concentration. This simplification makes it easy for a multizone model to calculate airflow and contaminant transport in a building. The computing time used is minimal (a few seconds to a few minutes) for a building, while still conserving the mass and species in buildings.

Due to different levels of approximations used in those computer models, the computed results therefore contain various degrees of uncertainties. Even CFD results cannot be trusted if the model and user are not calibrated. Without proper validation of a CFD

* **Qingyan Chen** is a professor in the School of Mechanical Engineering, Purdue University, West Lafayette, IN.

program and training of a CFD user, CFD can easily be turned into “Colored Fluid Dynamics” that only show beautiful computer images but do not demonstrate building science. A similar analogy can be applied to zonal and multizone modeling.

Thus, most reliable information regarding air distribution should be obtained from experimental measurements. Unfortunately, experimental measurements are often very expensive and time consuming. Sometimes, it is impossible to perform such an experiment before a building is built. If the building has been built, then it may be too late to do anything to remedy the problems associated with its air distribution. In many cases, scaled models are used in experimentation. It is difficult to match the dimensionless parameters that govern air distribution in buildings, such as the Reynolds number and Grashof number at the same time, between a scale model and an actual building.

Therefore, nowadays a common approach is using a computer model to compute air distribution in buildings, and performing limited but dedicated experimental measurements to obtain high quality data to validate the computer models. If the main features of the computer model are validated, one can then trust the computer results. In many cases, one would find that the computed results do not agree with the corresponding experimental data. In this scenario, **only you will believe your results if you use computer models, and everyone except for you will believe your results if you measure air distribution**.

I am not sure if you would agree with the statement highlighted above. In my career, I have used CFD, a zonal model, and a multizone model to calculate air distribution in buildings. At the same time, I have also performed experimental measurements of air distribution in one or more building zones. To be frank, I would not fully believe my own computational results unless I have used experimental data of similar air distributions to validate my computed results. Equally, I would not fully trust my own experimental data unless I have calibrated my measured data with different equipment or even with computational results from advanced models, such as direct numerical simulations that solve Navier-Stokes equations without approximations and use very fine grid resolution and very small time steps to capture all the flow details. Only after gaining confidence with my computer model can I then use the model for further design and analysis of air distribution in buildings. This kind of approach is also suggested in the “Indoor Environmental Modeling” chapter in the ASHRAE Fundamental Handbook.

In order to further demonstrate the pros and cons of computer simulations and experimental measurements, this topical issue has collected eight papers prepared by leading researchers in the field. The paper by Zhai et al. summarizes recent progress in CFD turbulence modeling and its applications to some indoor environment studies, and further identifies a few turbulence models that show great potential for modeling air distribution in buildings. Zhang et al. evaluates the performance of those models and recommends the best ones for further studies by comparing their computed results with high quality experimental data of air distribution from literature. Megri and Haghighat review the basic principles of zonal models and their development and applications in buildings. Axley presents not only the historical development of multizone airflow modeling theory but also the current state of the multizone flow model theory for buildings. These four papers give a comprehensive overview of air distribution modeling from a single zone to a whole building with HVAC systems. Sun and Zhang summarize modern methods for airflow measurements and their applications and limitations. Sandberg's paper focuses on measuring air distribution in a whole room with various kinds of optical equipment. Melikov et al. discuss in great detail other types of equipment used in measuring low air velocity in buildings. The three papers concerning air distribution measurements offer very interesting comparisons of associated techniques and errors. It is very interesting to note the challenges in experimental measurements. In the last paper, Nielsen demonstrates how to use computer models and experimental measurements to design an appropriate ventilation system for a room with a high level of thermal comfort. Though written by so many different authors, the eight papers are related and form a complete story. These authors review the past development, discuss present applications, and look into future prospects. I truly believe this topical issue is useful for both experienced and novice building researchers, consultants, and designers.

I would like to take this opportunity to thank the many reviewers who have helped me in reviewing the manuscripts. Many of them gave very useful, critical, and constructive comments that helped the authors in revising their papers. While the names of those reviewers cannot be disclosed, their contributions should never be overlooked.

This topical issue is probably the last topical/special issue that I will edit for *HVAC&R Research*, as I will begin my duty as the Editor-in-Chief for *Building and Environment*. Thus, I have resigned as an Associate Editor for *HVAC&R Research*. I have very much enjoyed working with the Editor of *HVAC&R Research*, Professor Reinhard Radermacher, and his assistant, Lori Puente, in the past four years. I am very grateful for their guidance, advice, assistance, and friendship. I would also like to express my appreciation for Michshell Phillips, who helps with the English editing of this topical issue. My experience with *HVAC&R and Research* has been very positive and memorable.