INTEGRATED BUILDING (AND) AIRFLOW SIMULATION: AN OVERVIEW

J.L.M. Hensen

Center for Building & Systems TNO-TU/e, Technische Universiteit Eindhoven, Netherlands

j.hensen@tue.nl

Abstract

This paper aims to give a broad overview of building airflow simulation, and advocates that the essential ingredients for quality assurance are: domain knowledge; selection of appropriate level of resolution; calibration and validation; and a correct performance assessment methodology. Directions for future work are indicated.

Introduction

Knowledge of airflow in buildings is necessary for heat and mass transfer analysis such as load and energy calculations, for thermal comfort assessment, for indoor air quality studies, for system control analysis, for contaminant dispersal prediction, etc. This paper aims to give a broad overview of building airflow modeling while implicitly advocating that for quality assurance domain knowledge and understanding are essential. The user must also be able to analyze the problem and re-express the building into a calibrated and validated model that is appropriate in terms of extent, complexity and time and space resolution levels. Finally it is necessary to adopt a correct performance assessment methodology.

Airflow modeling levels of resolution and complexity

Building simulation uses various airflow modeling approaches. In terms of level of resolution these can be categorized from macroscopic to microscopic. Macroscopic approaches consider the whole of building, systems, and indoor and outdoor environment over extended periods, while microscopic approaches use much smaller spatial and time scales. The following is a brief stepwise overview of the various approaches, illustrated with some case study material.

Rules of thumb, engineering values, empirical relations

In this approach airflow is modeled conceptually. Based on rules of thumb, engineering values and/or empirical relationships it is up to the user to define direction and magnitude of airflows. This is a standard method, fully integrated with the thermal network solver of building performance simulation software. Figure 1 shows an application example in which the objective was to compare displacement ventilation with mixing ventilation. Hensen et al. (1996) report that verification with experimental results showed good agreement.
Mass balance network

In the mass balance network method, the building and associated systems are treated as a network of nodes representing rooms, parts of rooms and system components, with inter-nodal connections representing the distributed flow paths associated with cracks, doors, pipes, pumps, ducts, fans and the like. The assumption is made that for each type of connection there exists an unambiguous relationship between the flow through the component and the pressure difference across it. Conservation of mass for the flows into and out of each node leads to a set of simultaneous, non-linear equations, which can be integrated over time to characterize the flow domain.
1991, 1999) and nowadays commonly used in practice. The reasons for this are threefold. Firstly, there is a strong relationship between the nodal networks that represent the airflow regime and the corresponding networks that represent its thermal counterpart. This means that the information demands of the energy conservation formulations can be directly satisfied. Secondly, the technique can be readily applied to combined multi-zone buildings and multi-component, multi-fluid (e.g. water and air) systems. Finally, the number of nodes involved will be considerably less than that required in a CFD approach and so the additional CPU burden is minimized.

*Computational fluid dynamics (CFD)*

In the CFD approach the conservation equations for mass, momentum and thermal energy are solved for all nodes of a two- or three-dimensional grid inside or around the object under investigation. CFD is a technology that is still very much under development. For example, several different CFD solution methods are being researched for building airflow simulation: direct numerical simulation, large eddy simulation (see e.g. Jiang and Chen 2001), Reynolds averaged Navier-Stokes modeling, and lattice Boltzmann methods (see e.g. Crouse et al. 2002). In practice, and in the building physics domain in particular, there are several problematic CFD issues, of which the amount of necessary computing power, the nature of the flow fields and the assessment of the complex, occupant-dependent boundary conditions are the most problematic (Chen 1997). This has often led to CFD applications being restricted to steady-state cases or very short simulation periods (see e.g. Haghhighat et al. 1992, Martin 1999, Chen 2000). An application example is shown in Figure 3.

![Figure 3. Model of a historical building and CFD predictions of air velocity distribution in the central longitudinal section at a particular point in time (Bartak et al. 2001).](image)

Integration of CFD with building energy is also still very much in development although enormous progress has been made in recent times (see e.g. Bartak et al. 2002, Zhai et al. 2002).

**Validation and calibration**

Due to lack of available resources it usually has to be assumed in a practical design study context that the models and the simulation environment, which is being used, has been verified (i.e. the physics are represented accurately by the mathematical and numerical models)

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and validated (i.e. the numerical models are implemented correctly). Nevertheless it is critically important to be aware of the limitations of each modeling approach.

For example, when using the network approach it should be realized that most of the pressure-flow relationships are based on experiments involving turbulent flow. Von Grabe et al. (2001) demonstrate the sensitivity of temperature rise predictions in a double-skin façade, and the difficulty of modeling the flow resistance of the various components. One way forward would be to use CFD in separate studies to predict appropriate local loss factors $\zeta$ and friction factors for later use in network methods; see e.g. Strigner and Janak (2001).

As indicated above, CFD is still very much being developed. At the same time it seems to be very appealing to engineers and clients; the “colors for directors” effect? Therefore it is essential that quality assurance procedures such as by Chen and Srebric (2001) are developed.

As discussed elsewhere in more detail (Hensen 1999) other major limitations are related to assumed ambient conditions; i.e. the discrepancy between the "micro climate" near a building and the weather data, which is usually representative of a location more or less distant from the building. These differences are most pronounced in terms of temperature, wind speed and direction, the main driving potential variables for the heat and mass transfer processes in buildings!

Calibration is a very difficult issue in practice. For existing buildings there are usually no experimental results readily available. In a design context there is not even a building yet. In practice, the only way to calibrate the model is to try to gain confidence by carefully analyzing the predictions and to compare these to expectations or “intuition” based on previous work. Unexpected results are usually the result of modeling errors. In rare – but interesting – cases unexpected interactions take place and – after analyzing these – the simulations may have helped to improve the understanding of the problem. In any event, calibration should not be taken lightly and sufficient resources should be reserved for this activity.

**Performance assessment methodology**

Simulation quality can only be assured through an appropriate performance assessment methodology. This should always include selection of the correct model resolution/complexity level and calibration as indicated above. Obviously simulations should be performed against relevant inside and ambient boundary conditions during a suitable length of time. The results should be thoroughly analyzed and reported. Next the model should be changed to reflect another design option, and the procedure of simulation, results analysis and reporting should be repeated until the predictions are satisfactory. It is very important to convey to clients that simulation is much better for performance based relative rank-ordering of design options, than for predicting the future performance of a final design in absolute terms. It is “interesting” that this is more likely to be “forgotten” in higher resolution modeling exercises.

A good performance assessment methodology should also cater to the limitations of the approach, for instance by a min-max approach or by sensitivity analysis.
As elaborated in Hensen et al. (1996) each airflow modeling method has its own (dis)-advantages, and different approaches should be used depending on the question to be answered; e.g. a low resolution model may be sufficient to predict the energy consumption of a particular ventilation system, while a high resolution model is needed for prediction of contaminant distribution in a room. As environmental engineers are usually concerned with all these questions, they need to be able to employ all these different modeling approaches. The appropriate approach should be based on the problem, not on the simulation tool at hand!

**Conclusions and future work**

Although much progress has been there remain many problematic issues in building airflow simulation. Each modeling approach suffers from shortcomings that do not exist – or are much less - in other methods. Run-time cooperation between CFD and building energy simulation will alleviate some of these problems. This is a very promising direction for future work.

Also in terms of performance prediction potential, there is no single best method. Each method has its own (dis)-advantages. Which method to use depends on the type of analysis that is needed at a particular stage in the design process. A simulation quality assurance procedure is indispensable. Apart from the essential need for domain knowledge, parts of such procedure might be semi-automated; see e.g. Djunaedy et al. (2002). This is another interesting direction for future work.

**References**


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