Djunaedy, E., Hensen, J.L.M. & Loomans, M.G.L.C. (2002).
Towards a strategy for airflow simulations in building design.
Proceedings of the 8th International conference on Air Distribution in Rooms - Roomvent 2002,
8-11 September, pp. 4. Copenhagen: Danish Society of Heating, Ventilating and Air-Conditioning Engineers

TOWARDS A STRATEGY FOR AIRFLOW SIMULATION IN BUILDING DESIGN

E. Djunaedy, J.L.M. Hensen[1] and M.G.L.C. Loomans
Center for Building & Systems TNO - TU/e
Technische Universiteit Eindhoven
P.O. Box 513, 5600 MB EINDHOVEN, Netherlands

Summary
This paper presents the initial stages of an on-going research project that aims to improve the use of computer simulation in building design. The goal of the current work is an airflow related performance assessment methodology (PAM). Particular attention is paid to appropriate modeling levels in terms of resolution and complexity. This is illustrated by means of a practical case of integrated design of buildings and heating, ventilation and air-conditioning (HVAC) systems. The paper finishes with indication directions for future work.

Introduction

Building simulation is rapidly becoming the most important engineering tool in integrated design of buildings and HVAC systems. Recent advances in hardware and software make simulation approaches feasible that required the use of mini-supercomputers only a decade ago.

The abundance of software tools available to a design engineer requires rethinking why we actually use simulation: to serve an engineering purpose. This is not trivial as demonstrated by a recent quote related to airflow simulation: "Clients never fail to be impressed by the application of CFD [computational fluid dynamics] to their projects" (Kenneth, 2001). The question should be whether CFD is actually the most appropriate tool for a certain design question in a particular project. It should not be reduced to "colorful fluid dynamics" aimed at impressing rather than at providing objective quantitative design information.

Airflow Simulation in Building Design

The main airflow modeling levels of resolution and complexity can be categorized as:

- Building energy balance (BEB) models that basically rely on airflow guesstimates.
- Zonal airflow network (AFN) models that are based on (macroscopic) zone mass balance and inter-zone flow-pressure relationships; typically for a whole building.
- CFD that is based on energy, mass and momentum conservation in all (minuscule) cells that make up the flow domain; typically a single building zone.

Hensen et al (1996) analyze the capabilities and applicability of these approaches in the context of a displacement ventilation system. One of the main conclusions is that a higher resolution approach does not cover all the design questions that may be answered by a lower resolution approach. Each approach has its own merits and drawbacks. An environmental engineer typically needs each approach but at different times during the design process.

Airflow modeling is still very much in development. One area of research concerns intermediate modeling levels, such as, for example, reduced CFD in terms of a coarser mesh, a simpler turbulence model, etc. Another interesting area concerns the coupling of BEB, with AFN (e.g. Hensen et al. 2002) and/or with CFD by either incorporating CFD into BEB (e.g. Negrao 1995, Beausoleil-Morrison 2001), or by integrating dynamic fabric and radiation models into CFD (e.g. Moser et al. 1995 and Schild 1997).

Given the growing number of approaches, design engineers would be helped with a PAM to select modeling approaches that are commensurate with the task at hand. This paper presents an early prototype of such a PAM.

A Performance Assessment Methodology

The main ideas behind the prototype PAM shown in Figure 1 are, firstly, that a simulation should be consistent with its objective, i.e. the designer should not be tool-led, secondly, that there should be a problem-led rationale to progress from one level of resolution and complexity to the next, and thirdly we have to acknowledge that in reality there will be a trade-off between domain size, resolution level and available resources.

[1] Corresponding author – J.Hensen@tue.nl

The vertical axis shows the different levels of resolution. The horizontal axis shows the different levels of complexity. In between are decision layers.

The first consideration is to select the minimum resolution based on the design question at hand. For example:

- If energy consumption were needed, than BEB would be sufficient.
- If temperature gradient is needed, than at least an AFN is required.
- If local mean age of air is in question, than CFD is necessary.

A follow-up step is to check whether the above minimum resolution is actually sufficiently accurate for the design question at hand. For example:

- Load analysis based on BEB may be over-sensitive to convection coefficient (h_c) values, thus requiring AFN or CFD to predict more accurate h_c values.
- Load analysis may be over-sensitive to guesstimated infiltration or inter-zonal ventilation, thus requiring AFN to predict more accurate airflow rates.

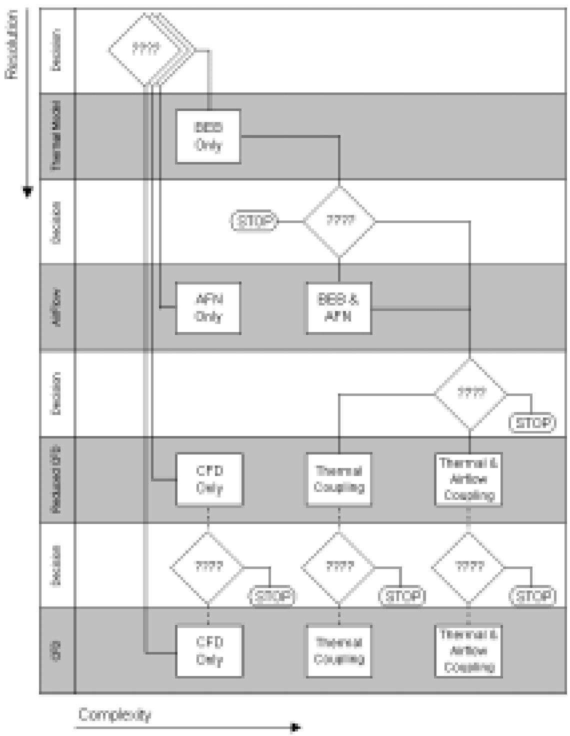

Figure 1 Prototype airflow based performance assessment methodology

How to actually make the decisions is to a large extend still vague as denoted by the question marks in Figure 1. In practice the decisions are often made implicit and very much depend on the skills and experience of a design engineer.

One way to make more objective and explicit decisions is to perform sensitivity analysis in the simulations as will be demonstrated in the following.

Case Study

This case study concerns an open-plan office space in the university building shown in Figure 2, which is being refurbished. The computer model comprises a 6 m wide and 12.5 m deep section of a 5.4 m high office space. The one external wall is a double-glazed structure. All other walls are assumed to be adiabatic. The section is assumed to have 10 occupants during office hours.

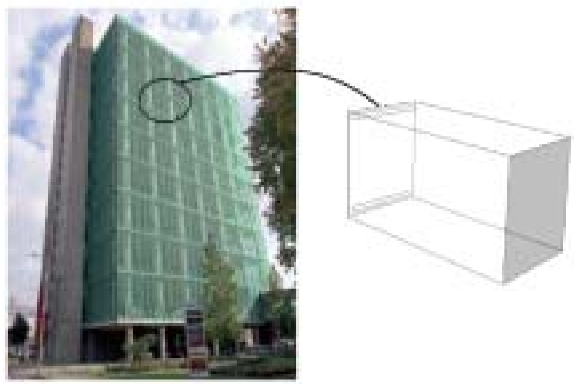

Figure 2 The building and the model

Given the large glazing area, the environmental designer would like to predict the likelihood of thermal comfort complaints, which may arise both in summer and winter conditions. However, due to space constraints, only the winter situation is discussed in this paper. Thermal comfort complaints might result from thermal radiation asymmetry and/ or from a cold down draft due to the large glazed area.

Results and Discussion

A BEB simulation model was run for a typical winter week. The zone air temperature was controlled at 21 °C. The simulations predicted an average predicted percentage of dissatisfied (PPD) level of 60% during office hours. Other simulations were carried out but now for an increased air temperature set point of 22 °C.

The results predict that in this case the average PPD level would be around 26% (Figure 3).

This exercise showed that by using BEB only, it is possible to do a general comfort assessment, to check a suggested solution for the problem, and to present the associated energy consequences in the same process.

The BEB model can predict local values for mean radiant temperature (MRT) and thus the thermal comfort level at specific locations in the zone. It can also be used to predict discomfort due to asymmetric thermal radiation.

The BEB model was used for a sensitivity analysis of PPD versus convection coefficients. Figure 3 shows that the PPD predictions are not very sensitive for assumptions regarding the convection coefficients (h_c). On average, there is a difference of around 17% in PPD.

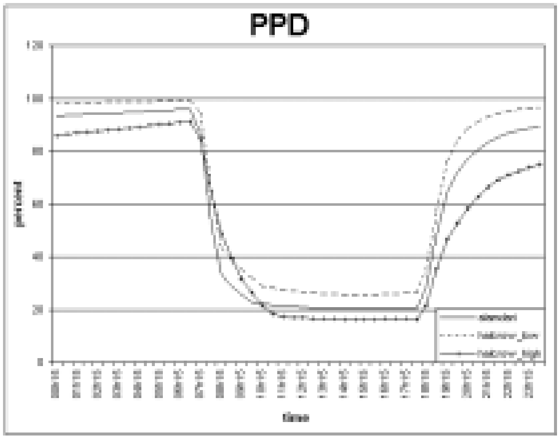

Figure 3 Predicted percentage of dissatisfied for a typical winter day

Since it assumes uniform air temperature and velocity conditions throughout the zone, the BEB model is obviously not able to predict any thermal discomfort due to cold down draft near the façade. This necessitates the use of CFD. (For this particular case and question, AFN can be skipped since it does not allow making intra-zone flow field predictions.)

The two-step static BEB-CFD coupling method (see Zhai et. al. 2001) was used in this case study. The two-step data exchange involves:

1. BEB to CFD: wall temperatures to establish boundary conditions for CFD.
2. CFD to BEB: the h_c value and heat extraction rate for energy calculation.

Figure 4 shows the distribution of PPD values in the room. It shows that the PPD is less than 20% in the occupied zone.

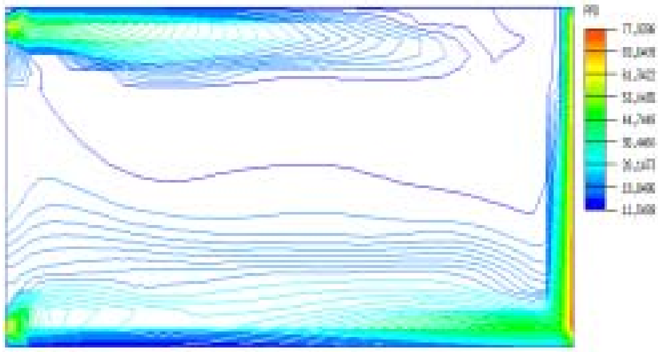

Figure 4 PPD distribution in the zone

Conclusions and Future Work

We feel that this paper introduces a promising performance assessment methodology based on selection of appropriate levels of modeling resolution and complexity in order to ensure that simulations are carried out based on the needs of the project and of the client.

Many issues still remain to be addressed. Regarding the PAM, the main one is whether it will be possible to find objective rules or explicit procedures for all decision points.

It should be noted that the PAM in Figure 1 only concerns the airflow part of building simulation. There are other areas of building simulation for which a similar approach could be developed.

Figure 5 shows a bigger scheme with an integrated simulation approach using external coupled software, i.e. run-time simulation results exchange at relevant time intervals.

Focusing on the BEB-CFD coupling some of the important questions to be answered are as follows.

1. Which data should be exchanged from BEB to CFD and vice versa?
2. Which spatial resolution level should the data have? Would it be easier to exchange field values for temperature, air velocity, etc instead of aggregated value like h_c?
3. At which frequency should this data be exchanged?
4. Which data exchange protocol should be used in external coupling of building simulation software?
5. Which software should control the overall simulation process?

6. Should the BEB be run with minimum complexity level, or should, for example, explicit HVAC models be included in the overall model?

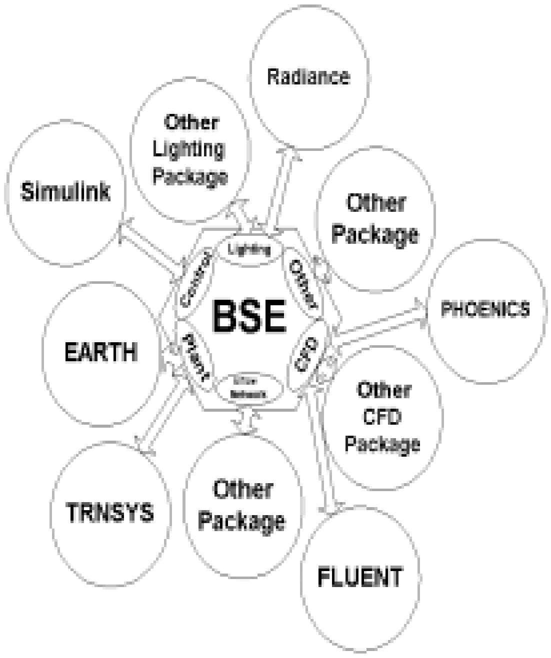

Figure 5 An distributed integrated building simulation environment based on an advanced multi-zone building simulation software run-time linked to external software packages

Immediate future work will include further development and testing of the prototype PAM, applying it to other cases, and addressing the coupling issues mentioned above. We see this as important contributions towards simulation based design environments for optimization of building energy performance and indoor environment.

References

Beausoleil-Morrison, I. 2001. The Adaptive Coupling of Computational Fluid Dynamics with Whole-Building Thermal Simulation, Building Simulation 2001, Proceedings of the 7th International IBPSA Conference, Rio de Janeiro, Brazil.

Hensen, J.L.M., Hamelinck, M.J.H., and Loomans, M.G.L.C. 1996. Modelling approaches for displacement ventilation in offices, Proceedings of the 5th International Conference Roomvent '96 , Yokohama.

Hensen, J.L.M., M. Bartak and F. Drkal 2002. "Modelling and simulation of a double-skin facade system", in ASHRAE Transactions, vol. 108, pp. ?? (In press.)

Kenneth, S. 2001. Model Answer, Building Services Journal, CIBSE, nr. 9

Moser, A., Schalin, A., Off, F., Yuan, X. 1995, Numerical Modelling of Heat Transfer by Radiation and Convection in an Atrium with Thermal Inertia, ASHRAE Transactions, Vol. 101(2), pp. 1136 – 1143.

Negrao, C.O.R. 1995. Conflation of Computational Fluid Dynamics and Building Thermal Simulation, PhD Thesis, University of Strathclyde, Glasgow, U.K.

Schild, P. 1997. Accurate Prediction of Indoor Climate in Glazed Enclosures, PhD Thesis, Norwegian University of Science and Technology, Trondheim, Norway.

Zhai, Z. and Chen, Q. and Klems, J.H. and Haves, P. 2001. Strategies for coupling energy simulations and computational fluid dynamics programs, Building Simulation 2001, Proceedings of the 7th International IBPSA Conference, Rio de Janeiro, Brazil.