Available online at www.sciencedirect.com
SCIENCE DIRECT®
Energy and Buildings 38 (2006) 1060–1068
ENERGY and BUILDINGS
www.elsevier.com/locate/enbuild

# Sensitivity analysis and application guides for integrated building energy and CFD simulation

Zhiqiang John Zhai [a,*], Qingyan Yan Chen [b]

[a] Department of Civil, Environmental, and Architectural Engineering, University of Colorado at Boulder, UCB 428, ECOT 441 Boulder, CO 80309-0428, USA
[b] School of Mechanical Engineering, Purdue University, 585 Purdue Mall, West Lafayette, IN 47907-2088, USA

Received 16 September 2005; received in revised form 14 December 2005; accepted 26 December 2005

**Abstract**

Building energy simulation (ES) and computational fluid dynamics (CFD) programs provide complementary information essential to evaluating building thermal performance. Integration of the two programs eliminates many model assumptions in separate applications and thus improves the quality of simulation results. This paper discusses the potential building and environmental characteristics that may affect the necessity and effectiveness of applying an ES–CFD coupling simulation. These characteristics and the solution accuracy requirement determine whether a coupled simulation is needed for a specific building and which coupling method can provide the best solution with the compromise of both accuracy and efficiency. The study conducts a sensitivity analysis of the coupling simulation to the potential influential factors, based on which general suggestions on appropriate usage of the coupling simulation are provided.
© 2006 Elsevier B.V. All rights reserved.

*Keywords:* Integrated building simulation; Computational fluid dynamics; Energy simulation; Sensitivity analysis

## 1. Introduction

Building energy simulation (ES) and computational fluid dynamics (CFD) programs provide plentiful and complementary information about building thermal performance, such as space cooling and heating load, distributions of indoor air velocity, temperature, and contaminant concentrations. This information is important to assessing thermal comfort, indoor air quality, and energy consumption of a building. Due to the complementary nature of results provided by the two programs, attempts to integrate these two programs receive increasing attention recently (e.g., [1–3]. It has been envisioned as a potential approach to eliminating simplification assumptions in each model and providing more accurate prediction on building behaviors [4].

Zhai and Chen [4–6] explored the principles, methodologies, strategies, implementation, and performance of the ES–CFD thermal coupling. Their study proved that a unique coupled solution exist in theory but different coupling methods may lead to different solution performance in terms of computing accuracy, stability and speed. It verified that the data coupling method, which transfers enclosure interior surface temperatures from ES to CFD and returns convective heat transfer coefficient and indoor air temperature gradients from CFD to ES, is the most straightforward, reliable and efficient coupling method. The study further proposed the staged coupling strategies to reduce the total computing time of a coupling simulation. A prototype of an integrated ES–CFD building simulation tool, implementing all the proposed coupling strategies, was developed. The performance of the program has been examined against experimental data and compared with no-coupling simulations.

However, the previous studies did not provide answers to the questions that are most important to building designers and engineers who may think of using the coupling simulation:

(1) Under which circumstance is an integrated ES–CFD simulation necessary? Or under which circumstance is a separate ES and CFD simulation sufficient? What is the improvement-cost-rate of coupling simulation?
(2) Which coupling strategy should be used?
(3) Which coupling frequency should be used?

This paper addresses these questions with a sensitivity study of the coupling simulation to potential building and environmental influential factors. It will provide essential and practical

* Corresponding author. Tel.: +1 303 492 4699; fax: +1 303 492 7317.
*E-mail address:* John.Zhai@Colorado.edu (Z.J. Zhai).

0378-7788/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2005.12.003

knowledge of coupling simulation to developers and users of ES–CFD coupling programs.

## 2. Coupling-relevant building and environmental characteristics

Building characteristics and simulation goals determine the most appropriate coupling simulation strategy for a particular building. Building characteristics that may influence building energy consumption have been extensively explored (e.g., [7–9];). However, not all these building characteristics have significant effect on the determination of a suitable coupling simulation strategy. Changes of some building characteristics, such as building shape, may not explicitly affect the performance of a coupling simulation.

In ES–CFD thermal coupling, the extent of connection between building energy and airflow models determines whether a coupling simulation is necessary and which coupling strategy is most appropriate for a building. More specifically, the necessity and effectiveness of ES–CFD coupling are determined by:

(1) the dependence of building envelope heat transfer and cooling/heating load on indoor air movement and air temperature stratification;
(2) the sensitivity of indoor air movement and air temperature stratification to thermal boundary conditions.

In general, a coupling simulation is desired if the inter-coupled information of ES and CFD is important to either ES or CFD or both. The dynamic behaviors of the inter-coupled information determine the best coupling strategy. For instance, a one-step or two-step static coupling process is sufficient if the inter-coupled data (e.g., surface temperature) is constant or has small change.

Hence, building and environmental conditions from outdoor to indoor, whose variation may influence the inter-coupled variables (e.g., convective heat from enclosures), need be examined for possible effects on building energy and airflow simulation. These building and environmental characteristics primarily include:

- outdoor weather conditions;
- building envelope properties;
- building window–wall area ratio;
- building operating conditions;
- space sizes;
- internal loads; and
- HVAC systems.

These potential influential factors can be grouped into five categories according to their macro-effects on buildings, as summarized in Table 1. The first category is environmental conditions that are mainly represented by outdoor air temperature and solar radiation for thermal consideration. The second is different HVAC systems used, such as radiation heating and cooling systems, traditional mixing HVAC systems, displacement ventilation systems, and natural/hybrid ventilation systems. The third is building occupying and system operating conditions that represent the capacity and dynamics of building energy consumption mainly determined by building functions. The fourth is building envelope information including material properties and window–wall area ratio. The last one is building sizes with different floor areas and ceiling heights. Combination of these characteristics determines the whole building thermal and indoor airflow behaviors, whereas individual characteristics may have distinctive influence. It is important to investigate the effect of these building and environmental characteristics on the coupling simulation.

## 3. Sensitivity study of coupling simulation

This study conducts a sensitivity analysis of the coupling simulation to the building and environmental characteristics. The main objectives of the sensitivity study are to address:

(1) whether a coupled simulation is necessary for a building with specific characteristics;

Table 1
Coupling-relevant building and environmental characteristics and potential variations

| Category | Characteristics | Potential variations |
|---|---|---|
| Environmental conditions | Outdoor air temperature | Large fluctuation, small fluctuation |
| | Solar radiation | Yes (summer design day), no (winter design day) |
| HVAC systems | Radiation heating/cooling | |
| | Mixing ventilation | CAV, VAV |
| | Displacement ventilation | CAV, VAV |
| | Natural/hybrid ventilation | |
| Occupying and operating conditions | Internal load | Heavy, medium, light |
| | Schedule | Day and night (residential) |
| | | Day only (commercial) |
| Building envelope properties | Wall, ceiling, floor | Heavy, medium, light |
| | Window–wall area ratio | Full, partial, none |
| Building sizes | Floor area | Regular, large |
| | Ceiling height | Regular, high |

متن کامل مقاله ← دریافت فوری

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات