ELSEVIER

Energy and Buildings 31 (2000) 267–283

ENERGY AND BUILDINGS

www.elsevier.com/locate/enbuild

Sensitivity analysis and validation of buildings' thermal models using adjoint-code method

P. Aude [a], L. Tabary [b], P. Depecker [a,*]

[a] *Centre de Thermique de Lyon, UA CNRS 5008, Equipe Thermique du Bâtiment, INSA de Lyon, Bât 307, 20 Av. A. Einstein, 69621 Villeurbanne, France*
[b] *Centre de Recherche EDF des Renardières, ADEB, Groupe modélisation et physique du bâtiment, route de Sens, Ecuelles, 77 250 Moret sur Loing, France*

Received 20 October 1998; accepted 18 June 1999

Abstract

The objective of this study is to present a validation method for simulation codes describing thermal behavior of buildings. Beginning with the classical form of comparison of theoretical and experimental results, it is proposed to improve the procedure by calculating the degree of uncertainty associated with the theoretical results. It can be shown that uncertainties associated with code input data, that is, the simulation parameters, propagate through the calculation and generate a range of uncertainty in the results. After describing the problem and objectives of the study, the computation code analysis will be presented. This concerns use of the CA-SIS (Conditionnement d'Air-Simulation de Systèmes) code, and employs the TRNSYS calculation environment. Experimental validation studies for the evaluation of this code have been carried out using ETNA (Essais Thermiques Naturels ou Artificiels) cells, which have been constructed and are maintained at a site near Paris. These cells and experimental procedures are described. To determine ranges of uncertainty in the numerical results, a sensitivity analysis is first carried out by an ''adjoint'' method. This method and the relationship linking the uncertainty to calculated sensitivities is presented. Notably, it can be demonstrated that the adjoint method simplifies the calculation of uncertainties. The results presented focus on the cell air temperature. The experimental air temperature evolves during the climatic heating sequence within the range of uncertainty of the theoretical results. It can be deduced that the first step of validation being reached, the developer of CA-SIS code can discuss the complete validation for this configuration. The high sensitivity of the internal air temperature to the parameter of heating power shows the limitation of isothermal air volume hypothesis. From this it can be concluded that it is necessary to improve the numerical modeling of the injection heating power.

Keywords: Adjoint code method; Buildings' thermal model; Experimental validation; Numerical simulation; Sensitivity analysis; Uncertainty analysis

1. Introduction: description of problem and objectives

The purpose of this study is to describe a validation method of complex computation codes for simulation of thermal conditions in buildings. These codes use a large number of input data. These data, which one can vary at will, are also termed parameters. The study is based on the idea that the validation must be made through a comparison of experimental and theoretical results, each set including its level of uncertainty. Usually, experimental results are presented with their uncertainties, which correspond to imperfections in the measurement apparatus. On the other hand, this is rarely the case for theoretical results, which are simply those generated by the simulation. However, data obtained and used for the simulation are themselves associated with an uncertainty which propagates through to the results of the computation. We can come to more appropriate conclusions on the effective validation of a theoretical result if we compare it with the experimental result outcome along with their respective uncertainties.

The determination of the uncertainty in computed results is linked to that of data entered into the code. We have the opportunity, using the adjoint-code method, to identify those parameters having the most influence on the magnitude of uncertainty. In order to improve the validation procedure, we can thus emphasize measurement preci-

* Corresponding author. Tel.: +33-04-7243-8461; Fax: +33-04-7243-8522; E-mail: chris@parga.insa-lyon.fr

0378-7788/00/$ - see front matter
PII: S0378-7788(99)00033-X

sion for some experimental data, such as the building parameters or climatic perturbations (Fig. 1).

Our work focuses on the validation of the CA-SIS (Conditionnement d'Air-Simulation de Systèmes) code developed by the Studies and Research Department of France Electricity (EDF). This code is designed for use by engineers groups studying thermal behavior of buildings. Prior to its use by professionals, the code must also be able to provide them automatically with information concerning the confidence interval of results, i.e., the uncertainty associated with them. For example, an energy requirement calculated for a given project will be indicated with a confidence interval of $\pm 5\%$. Similarly, a variation of the internal air temperature, used for the prediction of the thermal comfort, will be given at $\pm 7\%$. The data given here provide important complementary information that we deduce in our validation procedure. We wish to propose a method which is used not only for the validation of the code but also for an automatic analysis of uncertainties.

Sections 2 and 3 of this paper present the methods to be used in the theoretical (CA-SIS computation code) and experimental (ETNA — Essais Thermiques Naturels ou Artificiels — cell) approach of the problem. In Section 4 we describe the adjoint-code method which will allow us to perform a sensitivity analysis concerning the building parameters and climatic perturbations. The purpose of this is to identify data having a strong influence on results. Those inputs whose influence is weak are then separated from the process. In Section 5, uncertainties associated with the theoretical results will be evaluated using the computed sensitivities. Further in Section 5, we compare theoretical results with experimental results, matching each to its level of uncertainty. From this we deduce the level of validation of the code and present some conclusions in Section 6.

2. Description of the CA-SIS code

2.1. General presentation

One of the objectives of EDF has been to contribute to the development of centralized air conditioning systems by ensuring the quality of implemented solutions. From this perspective, EDF has developed thermal calculation software, named CA-SIS, suitable for the modeling of variations in performance and its optimization. This computer tool uses the TRNSYS calculation environment [1].

CA-SIS is a modular software intended for use in the sizing of heating installations and centralized air conditioning, and for the calculation of their operating cost. It permits the modeling of a large range of systems, including water-source heat pumps, roof-top, fan convector unit, coupled or non-coupled with a dual-duct air conditioning system and control of the installation. The development of CA-SIS continues in a manner designed to always render it more robust for use within major research organizations.

2.2. Architecture of CA-SIS

Fig. 2 shows the general structure of the code. The graphical interface frees the user from all programming operations. The assembler interface (i.e., model-building) permits modeling of the building by the connection of various modules. Each module corresponds to an elementary component of the building and facilities. The capture interface (i.e., model-building) provides the necessary format for assigning parameter values for each module.

The second layer of the software is made up of a library that integrates original models present in TRNSYS with

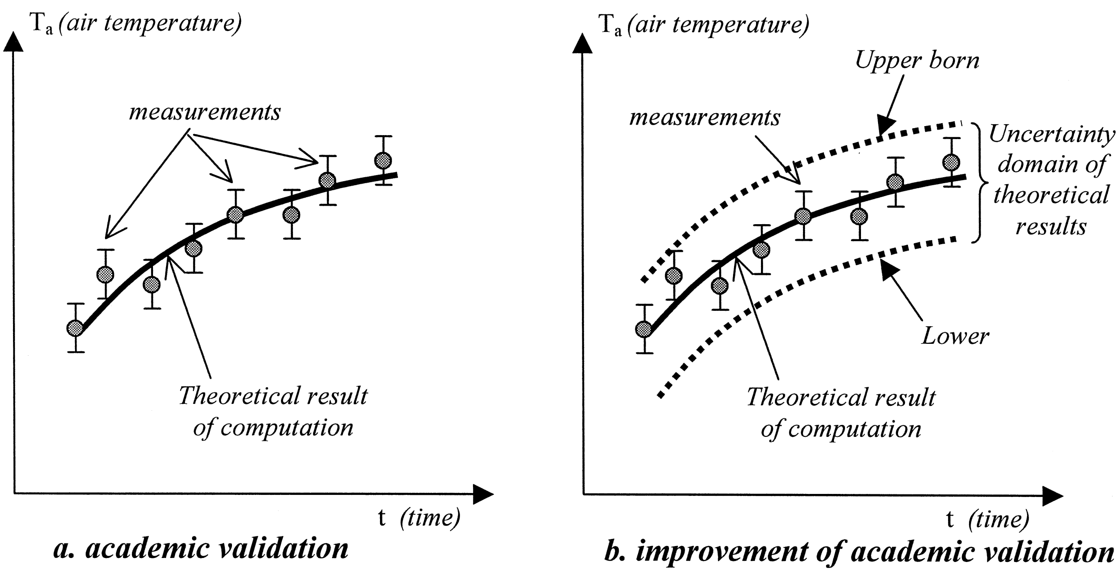

Fig. 1. Validation process of a predictive computation code using theoretical uncertainty range.