New simulation tools usable in the energy audit of HVAC systems

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1. INTRODUCTION

Early developments of simulation tools were mostly oriented towards supporting system design, i.e. mainly the selection and sizing of HVAC components. The usefulness of simulation tools in further stages of the building life cycle appeared later, among others with the apparition of friendly engineering equation solvers and of reliable simulation models.

Energy simulation may help all along the building life cycle, from early design until last audit and retrofit actions. Building and HVAC simulation models should therefore be continuously available, but in different forms, according to what is expected from the simulation and according to the information actually available.

Today, the simulation bottleneck is no more the computer, but the understanding of the user. Simulation models have therefore to be designed in such away to make easier this understanding. Hopefully the equation solvers presently available (Klein and Alvarado, 2002) open the way to the development of fully transparent and fully adaptable simulation models, with all equations written as in a text book. This means that a simulation program, its user guide and its reference guide can be combined into only one file, fully readable and directly executable.

2. USE OF SIMULATION TOOLS FOR ENERGY AUDITING

Everybody agrees on the urgent necessity to submit existing HVAC systems to a careful energy audit, but nobody has yet a clear idea of how this task might achieved.

Audit is required, among others, to identify the most efficient and cost-effective Energy Conservation Opportunities (ECOs), consisting in more efficient use or in (partial or global) replacement of the existing components (André et al., 2006a).

Benchmarking is a very first challenge for the auditor, who must be able to make a quick judgment about the building considered at early audit stage (the so-called “preliminary inspection”).

The very first questions to answer are:

- Is *that* building a “good” case (as said in medicine)?
- Is it worthwhile to submit it to a more *detailed* analysis?
- What might be the outcome of this analysis in terms of *retrofit*?

Answering these questions requires some (even very provisory) *diagnosis*, which has to be established on the basis of the very scarce information currently available: technical data contained in as-built files actually available and very global recordings of energy consumptions (fuel and electricity).

A series of new simulation tools are being developed, in the frame of the HARMONAC project (2008), in order to help the unfortunate auditor in establishing his diagnosis.

BENCHMARK is the first tool proposed: it allows the auditor to make a preliminary energy analysis on the basis of a very limited amount of information about the building considered. This analysis consists in simulating the building seen as a unique zone and described by a very limited number of parameters. This building is supposed to be equipped with a standard HVAC system and the simulation is performed with reference hypotheses about climate control, occupancy and human behaviour, including the use of lighting and of other electrical equipment. The comparison of such "reference" simulation with actual energy consumption records is expected to provide, most of the times, a salutary chock, stimulating further thinking…

3. MODELING

For benchmarking, as for further audit actions, the simulation tool must handle with realism:

- building (static and dynamic) behaviour,
- weather and occupancy loads,
- comfort requirements and control strategies (air quality, air temperature and humidity),
- full air conditioning process and characteristics of all HVAC system components (terminal units, air handling units, air and water distribution, plants)

The level of detail required for the calculation of H/C demands can vary a lot from case to case:

- For heating calculations, the major issues are a correct description of the building envelope and an accurate evaluation of air renewal.
- For cooling calculations, the fenestration area and orientation, the intensity and distribution of internal gains, the ventilation rates and the geographical location appear as critical issues.

At benchmarking stage mainly, the simulation tools have also to be usable with the limited information actually available. These tools must be easy-to-use, transparent, reliable, sufficiently accurate and robust.

BENCHMARK includes models of both the building and the HVAC equipment. These models are submitted to different loads and interact at each time step with a control module (Figure 1).

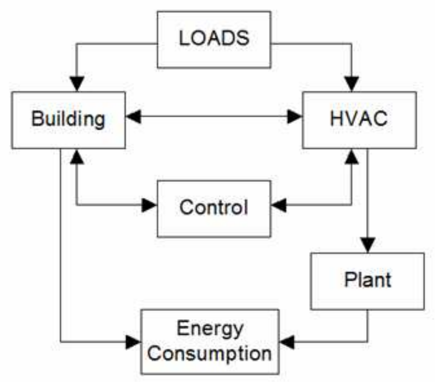

Figure 1: Interactions among the different part of the model

The main phenomena involved in building dynamics are considered in order to compute realistic heating and cooling demands. A compromise is made between the number of influences taken into account and the simplicity of the model: transient heat transfer through walls, energy storage in slabs, internal generated gains, solar gains through windows, infrared losses and, of course, ventilation and heating/cooling devices, are actually taken into account.

3.1 Inputs / Outputs / Parameters

The outputs, inputs and parameters must be selected according to the specific needs of the user.

In agreement with what is done in TRNSYS (Klein et al., 2004), the parameters are here defined as selected inputs which are not supposed to vary during the simulation.

The main outputs of the tool presented here are:

- Air quality and hygro-thermal comfort achievements: CO_2 contamination, temperature, humidity, PPD and PMV
- Global power and energy consumptions : Fuel and Electricity consumptions

- HVAC components specific demands
- Performances of the mechanical equipments: COP, efficiencies,…

The main inputs are:

- Weather data : hourly values of temperature, humidity, global and diffuse radiations
- Nominal occupancy loads, occupancy and installation functioning rates
- Comfort requirements: air renewal, temperature and humidity set points.
- Control strategies: feed-back on indoor temperature and relative humidity, feed-forward on occupancy schedules and calendars.

The main parameters are :

- Dimensions, orientation and general characteristics of the building envelope (e.g. “heavy”, “medium” or “light” thermal mass and walls U values).
- Sizing factors of the main HVAC components

3.2 Building Modeling

The dynamic behavior of the building is taken into account by a simplified model to limit the quantity of required data and ensure robustness and transparency. It is based upon a RC network including five thermal masses, corresponding to a large occupancy zone, surrounded by external glazed and opaque walls (Figure 2). This scheme corresponds to a typical office building, mainly composed of lattice structure and slabs. The R-C model was the object of a comparative validation works carried out using the BESTEST procedure.

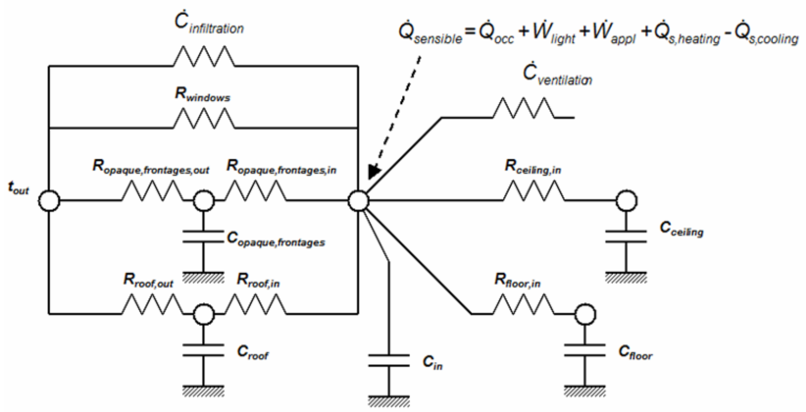

Figure 2: Simplified building simulation model

A sensible heat balance is established to calculate the indoor node temperature (equation 1).
The indoor energy storage is computed by the means of a first order differential equation.

$$\frac{dU}{d\tau}_{in} = \dot{Q}_{roof,surf,in} + \dot{Q}_{floor,surf,in} + \dot{Q}_{opaque,frontages,surf,in} + \dot{Q}_{windows} + \dot{H}_{s,vent} + \dot{H}_{s,\inf} + \dot{Q}_{s,in} \quad (1)$$

$$\Delta U_{in} = \int_{\tau 1}^{\tau 2} \frac{dU}{d\tau}_{in} \, d\tau \quad (2)$$

$$\Delta U_{in} = C_{in} * \left(t_{a,in} - t_{a,in,1}\right) \quad (3)$$

$$C_{in} = F_{a,in} * V_{in} * \rho_a * c_{p,a} \quad (4)$$

Two supplemental mass balances are used to compute the CO2 concentration and the water content in the indoor environment.

All possible CO2 and water flow rates entering and leaving the zone are taken into account; these flow rates can be produced by the occupants, the ventilation and/or by the HVAC terminal units.

3.3 HVAC System Modeling

The building zone model presented here above can be easily connected to a complete “typical” HVAC system model, including, for example, a Constant Air Volume (CAV) Air Handing Unit (AHU), some local heating and/or cooling Terminal Units and a heating and cooling plant (Figure 3).
The system model actually available includes most of the classical HVAC components currently used (fans, air-to-air static recovery systems, coils, fan coils, pumps…).
Considering that the building model is a mono-zone model, most of components (AHUs, TUs, pumps…) are aggregated into “global” components. The different locations of the terminal units and of the air diffusers are not considered at this stage.

Two different modelling levels can be distinguished for the HVAC system (André et al., 2006b; Lebrun et al., 2006a):

- So-called “mother” (“first principle”, or “mechanistic”) models, containing all the (present) understanding of the physical phenomena, are used as references;
- So-called “daughter” (“simplified” and very often polynomial) model, generated with help of the help of the previous ones, are preferred to simulate large system on long time periods.
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“Daughter” models only are used in Benchmark.

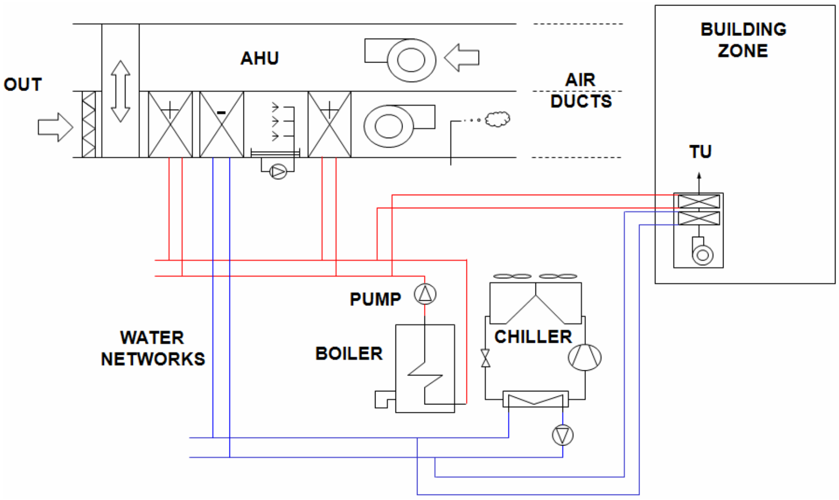

Figure 3: The HVAC system considered in BENCHMARK

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