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Citation for published version (APA):

Costola, D., Mirsadeghi, M., Blocken, B. J. E., & Hensen, J. L. M. (2008). Towards external coupling of BES and HAM envelope programs for whole building HAM simulation. In S. Roels, G. Vermeir, & D. Saelens (Eds.), *Proceedings of the Building Physics Symposium in honour of Professor Hugo L.S.C. Hens, 29-31 October 2008, Leuven, Belgium* (pp. 143-146). Katholieke Universiteit Leuven.

Document status and date:

Published: 01/01/2008

Document Version:

Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Towards external coupling of BES and HAM envelope programs for whole building HAM simulation

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Keywords: external coupling, BES, HAM

Summary

This paper presents preliminary results of on-going research on the integration of building energy simulation (BES) and building envelope heat, air and moisture transfer (HAM) programs. The paper contrasts the capabilities of two BES and HAM programs, and presents the theory and preliminary results of one-way coupling between them.

1. INTRODUCTION

The study of several building performance aspects such as indoor air quality, mold growth, surface and internal condensation, frost damage, moisture buffering and energy consumption demands careful simulation of HAM transfer in whole building.

In the framework of whole building simulation, a multi-partner project is being carried out by 4 departments in 3 universities in Flanders and the Netherlands, 1 research institute and 3 partners from industry. The project is entitled "Heat, air and moisture performance engineering (HAMPE) - A whole building approach". In this project, the simulation of whole building HAM performance is to be achieved by the combination of different programs which have been developed for specific combinations of physical (heat, air and moisture) and geometrical (exterior, building envelope and interior) domains. This paper presents preliminary results on the integration of BES and building envelope HAM programs, using the programs ESP-r¹ and HAMFEM².

The paper first compares the capabilities and deficiencies of ESP-r and HAMFEM. Then the advantages and disadvantages of one-way coupling are discussed. Results of one-way coupling of HAMFEM and ESP-r are presented for the BESTEST case-600 model.

2. BES AND HAM CAPABILITIES

Different building performance simulation (BPS) programs exist for analyzing HAM building performance indicators. These programs can be classified into three groups: Computational Fluid Dynamics (CFD), e.g. Fluent; building envelope HAM, e.g. HAMFEM; and finally Building Energy Simulation (BES), e.g. ESP-r.

These programs often focus on a specific geometrical domain in combination with one or more physical domains. Furthermore, they have strong capabilities but also some particular deficiencies in terms of boundary conditions, physical models and resolution in space and time. BES tools are intended to study whole building energy performance and thermal comfort issues. These analyses are mainly focused on heat transfer, therefore simplified models for moisture and air transfer in porous media are adopted. Contrary to this, building envelope HAM tools allow detailed heat and moisture transfer modelling, but in general the simulation is restricted to building components rather than the whole building. Table 1 lists specific features that are extensively addressed in HAMFEM and ESP-r codes, which clarifies their complementary characteristics.

ESP-r provides several facilities for whole building simulation, such as detailed models for exterior boundary conditions calculation and integrative models for the indoor environment simulation including HVAC systems, infiltration and ventilation. HAMFEM has detailed models for the building envelope HAM transfer, and it also includes some boundary conditions for HAM simulation, such wind-driven rain (WDR) and simplified heat and vapor surface coefficients.

Table 1. Features that are extensively addressed in HAMFEM and ESP-r codes

Geometrical domain	Physical domain	Phenomenon / modelling techniques	HAMFEM	ESP-r
	General	Uncertainty analysis		X
Exterior	Heat	Shortwave radiation: obstruction by neighbor (direct and diffuse), ground reflected component, isotropic sky model for diffuse radiation		X
		Longwave radiation: surrounding building effect, calculated ground surface temperature		X
		Convection: several empirical correlations		X
	Air	Pressure coefficient: database and empirical models		X
	Moisture	Wind-driven rain: catch ratio database	X	
Envelope	Heat	Heat injection/extraction in one wall node as function of the state of another node in the zone		X
	Air	Air transfer through homogeneous porous media	X	
	Moisture	Vapor transfer	X	X
		Liquid transfer	X	
		Condensation Hysteresis	X X	
Interior	Heat	Longwave radiation: Raytracing view factors, calculated temperature for other surfaces		X
		Shortwave: Sun penetration through windows		X
		Convection: several empirical correlations		X
	All	Schedules for internal gains		X
		HAM states of indoor air as function of the HVAC system		X
		HAM states of indoor air as function of the airflow rate calculated using Air Flow Network (AFN)		X

3. TOWARDS INTEGRATION

Different approaches for coupling BPS programs have been used in the past. The simplest coupling technique is one-way coupling, where in fact the two domains or phenomena do not exchange data in run-time. In this sense, the coupling can be used to provide boundary conditions for one program that are pre-calculated by the other program, as presented in Figure 1. An alternative approach is two-way run-time coupling, where the programs exchange information on a time step basis. One-way implementation is straightforward and this approach is particularly suitable for the boundary conditions of the exterior domain, such as wind-driven rain, wind pressure and forced convection. However, this technique can also be used in other domains. In cases where the domains are coupled, the results of one-way coupling will be less accurate than with two-way coupling, but they can be more accurate than imposing simplified boundary conditions. Coupling programs always involves a tread-off between complexity and accuracy, and simple approaches cannot be considered inappropriate a priori. The necessity of using coupled simulations is case dependant, and one-way coupling represents a step in between stand-alone and run-time coupled simulation.

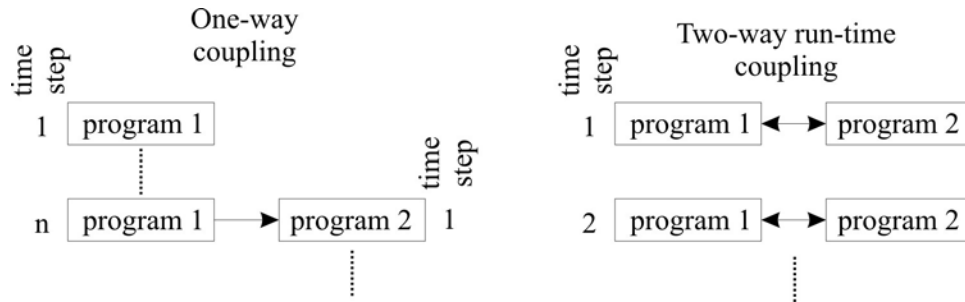


Fig. 1. Schematic representation of one-way and two-way coupling

One-way coupling of BES and HAM can be performed at several levels, as presented in Table 2. The simplest approach is to use the BES results for the internal air temperature and humidity as boundary condition to the HAM model. Levels 2 and 3 can improve the calculation by providing to the HAM program the surface sensible heat fluxes calculated by BES, which takes into account more phenomena.

Table 2. One-way coupling levels

Levels – variables	Effects or phenomena taken into account
Level 1 – internal air states	HVAC Infiltration and ventilation Transparent constructions Overheating
Level 2 – internal sensible heat flux	Convection Longwave radiation Shortwave radiation
Level 3 – exterior sensible heat flux	Convection Longwave radiation Shortwave radiation

4. PRELIMINARY RESULTS

The BESTEST case-600 was chosen to study the effect of one-way coupling on the HAMFEM. General information about the settings used in the simulations can be found in the BESTEST documentation³.

Two reference simulations were performed in HAMFEM using fixed indoor air conditions corresponding to the heating and cooling set points of the ESP-r simulation: 20°C and 27°C. In both cases the relative humidity was fixed at 50%, while in fact it floats during the BES simulation. The default HAMFEM heat and moisture transfer coefficients were used. The climatic data was taken from BESTEST (Denver, USA), and no wind-driven rain is considered. Simulations were performed for one year, and all nodes were initialized at 20 °C and 50 % RH.

One-way coupling was performed using two levels of data exchange: level 1 using internal air temperature (T_i) and relative humidity (RH_i) from ESP-r and level 2 using surface sensible heat flux from ESP-r. Figure 2 shows the heat flux at the internal surface of the wall from HAMFEM simulation, for 3 days in the summer period. The results follow the same trend in all simulations, with heat gain in the ambient during the day (negative values in the figure) due to the solar radiation and exterior air temperature (up to 34°C) and heat losses during the night due to the low exterior air temperature (around 17°C).

The simulation results using the indoor climate from ESP-r lie between the reference HAMFEM simulations with fixed indoor conditions, as expected considering the set points used in the ESP-r simulation. However, the surface sensible heat flux provided by ESP-r is much higher than the total heat flux calculated by HAMFEM (sensible plus latent). The convective heat transfer coefficient and especially the shortwave radiation calculated by ESP-r, which act directly on the surface flux, cannot be described using only the indoor temperature, which explains the difference in the results.

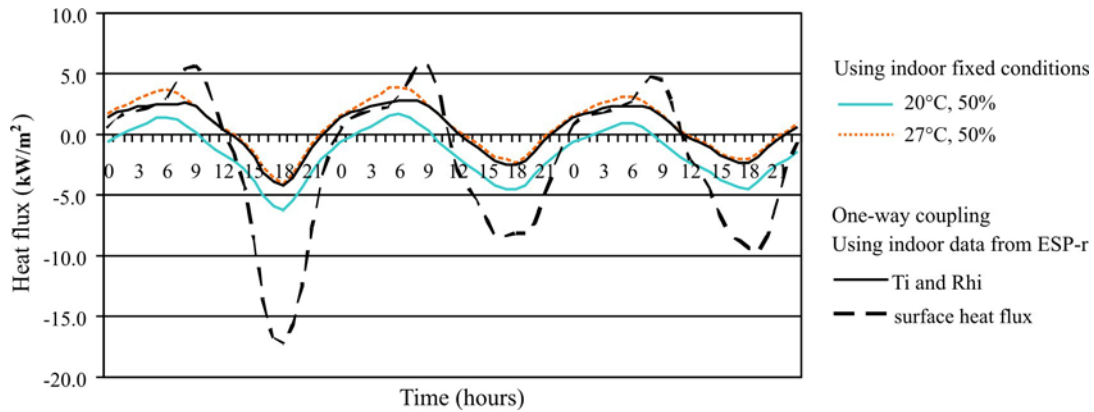


Fig. 2. Heat flux on the internal surface in HAMFEM using different internal boundary conditions

The annual heat flux at the internal surface is shown in Figure 3, grouped in cooling and heating energy. As discussed in Figure 2, the surface heat flux provided by ESP-r leads to a much higher total cooling load. The difference in HAMFEM reference results is a good indication of the model sensitivity to the indoor conditions.

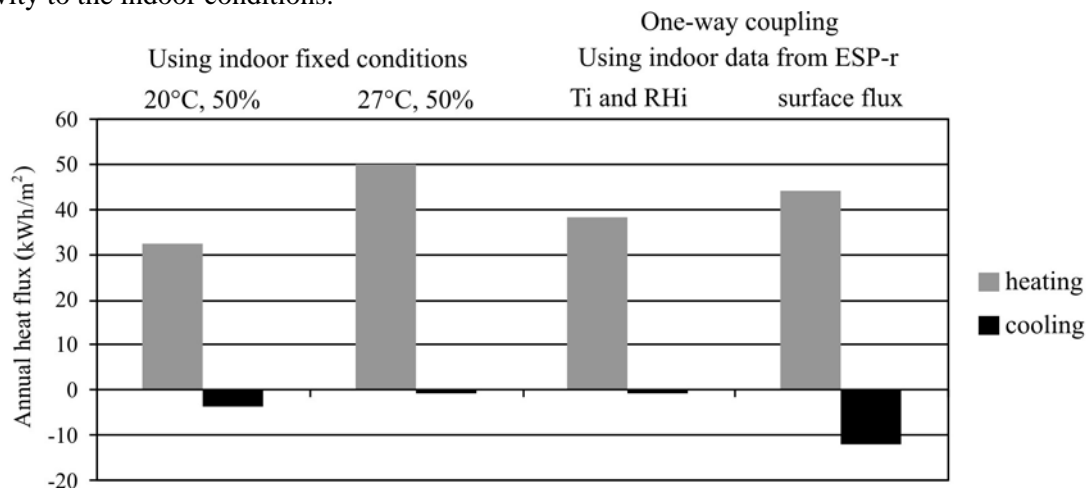


Fig. 3. Annual heat fluxes on the internal surface on HAMFEM using different internal boundary conditions

5. CONCLUSIONS

The coupling of BES and HAM programs can be used to improve simulation accuracy by including additional domains and phenomena. The coupling can be performed in different ways and levels of information exchange. Results of one-way coupling were presented in this paper, and they show features, particularly on the radiation modelling, that are not captured using fixed internal boundary conditions in building envelope HAM simulation.

ACKNOWLEDGEMENTS

This research is funded by the “Institute for the Promotion of Innovation by Science and Technology in Flanders” (IWT-Vlaanderen) as part of the SBO-project IWT 050154. Their financial contribution is gratefully acknowledged.

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