DEVELOPING VIRTUAL LABORATORIES FOR THE DESIGN AND TEST OF VENTILATION CONTROL STRATEGIES

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ABSTRACT

The control industry integrates more and more recent innovations, especially on the sector of communication networks (bus), control (fuzzy logic, neural networks…) and informatics (hard-and software) for the development of Building Automation and Control Systems of HVAC plants. These complex control strategies are now being implemented on ventilation systems (hybrid systems, mechanical systems, etc) to satisfy energy and environmental issues.

The necessity of innovation on this field imposes on the manufacturers to develop faster and faster new products while managing perfectly the quality of the products. To date, many field tests are carried out in order to make sure of the correct function of the product under different conditions. An adapted approach is to use a virtual laboratory since it reduces the necessary time for expensive and time-consuming field tests.

SIMBAD (SIMulator of Buildings And Devices) Building and HVAC Toolbox is a library of models of HVAC components developed in the Matlab/Simulink graphical environment. It is used in the field of control of HVAC system and also used for the development of virtual laboratories for the design and test of control systems in buildings.

This paper presents the structure and uses of virtual laboratories and the evolution of SIMBAD to provide the necessary models to build virtual laboratories for design and test of ventilation control strategies.

KEYWORDS

Ventilation control strategies, airflow modelling, graphical programming, virtual laboratories

INTRODUCTION

Innovations in the field of control have gradually been integrated in heating and cooling systems over the last twenty years; In the ventilation field, there is nowadays an increasing demand of more sophisticated control strategies especially in systems involving both mechanical and natural ventilations. An appropriate approach for the development of the control strategies is to use so-called "virtual laboratories". Vaézi et al. (1991) gives the principles of emulation techniques used in virtual laboratories developed during IEA annex 17 for use in the control of HVAC plants. Visier (2000) proposes a larger development and use of virtual laboratories on the HVAC field. Such a laboratory can be used throughout the whole development phase of products. This includes:
- completely simulated laboratory for the development of new control strategies
- partly simulated / real laboratory (emulation) for the test of prototypes or products.

This paper gives an overview of the structures of virtual laboratories with applications in the development BACS for development and improvement of the SIMBAD Building and HVAC

toolbox for integration of airflow modelling so that virtual laboratories can be enhanced to test ventilation control strategies.

SIMBAD BUILDING AND HVAC TOOLBOX

The virtual laboratories developed at CSTB are based on the SIMBAD Building and HVAC Toolbox described in SIMBAD (2001). It is developed in the Matlab/Simulink environment [Simulink 2001]. The toolbox shown in Figure 1 consists of building zone models, models of heating, ventilating and air conditioning components, controllers of such equipment and various utilities (weather data files, occupancy profiles, data acquisition interfaces…) that are necessary to build up virtual systems to study the behaviour of HVAC plants. The toolbox benefits from the user friendliness of the Simulink graphical environment. Version 4.0 is under development to include airflow modelling as well as coupled thermal/airflow zone models.
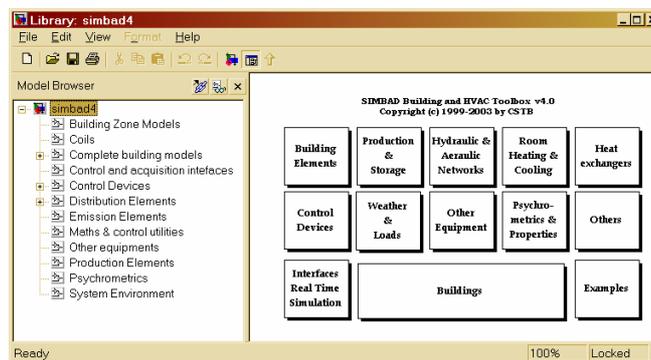
Figure 1 : SIMBAD Building and HVAC Toolbox

One main characteristic of the toolbox is the definition of connection vectors to transfer data from one block to another: air vector carrying air vector, water vector, information network, weather vector… To facilitate the use of the toolbox, several systems are provided. The building thermal zone model ranges from a detailed zonal model [Riederer 2001] requiring a full description of walls to predefined R-C models representative of high/low inertia, high/low insulation, residential/non-residential buildings. In fact, for several control studies, the user need to verify that the control strategies are suitable to a class of buildings instead of one particular building.

DEVELOPMENT AND USE OF VIRTUAL LABORATORY

Riederer et al (2001) gave a few criteria to be taken into consideration when developing a virtual laboratory:
- Level of knowledge of the user. People with high or low knowledge shall both have the possibility to use the laboratory without limitations due to the models used. Note that the aim of such a test bench is that a user (mainly from the control field) can obtain representative results without a detailed knowledge of building modelling.
- Possibility to include different levels of control (local, central plant or supervisory) which are either real or virtual.
- Ability to test several systems on the same test bench.

A virtual laboratory consists of three parts:
- virtual part (building simulation model)
- interconnection between virtual and real part (input/output interface)

- partly real/virtual part (controllers)

Figure 2 shows the structure of the virtual laboratory that should distinguish the control system from the rest of the building and HVAC system.
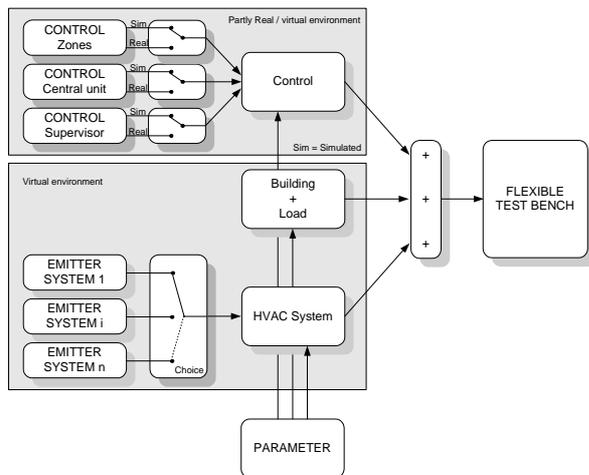

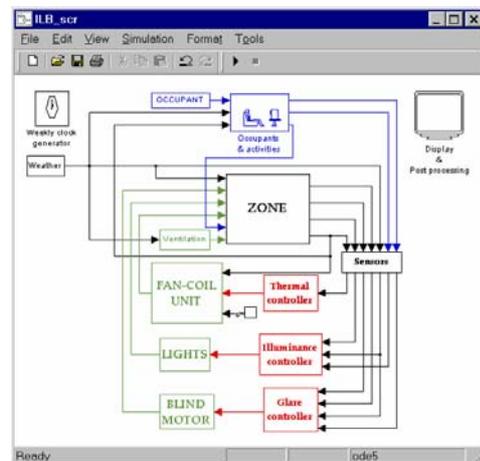Figure 2 : Overall structure of a test bench

Figure 3: Horizontal structuring of the building model used in INTECOM project

To date, the SIMBAD controller test benches [Vaézi et al 1997] uses a modelling approach that structures the building by zones. Husaunndee et al (2001) developed a test bench for defining and testing integrated control strategies at zone level using this approach in the INTECOM project. Each zone includes an emitter system, load models (lighting, occupants …) and climate (depending on the orientation of the zone) together with the control units. The structure of this laboratory as shown in Figure 3 can be called "horizontal".

The advantages of this structure are:
- The phenomena on the zone level can easily be understood and monitored.
- It is easy to add new zones to a building model by duplicating the whole layout.
- The simulator is easily modified to test real controllers by removing the corresponding block representing the virtual controller.

The disadvantages are:
- For a building model, this structure is not flexible enough to implement new phenomena on the zone level, in particular any phenomena involving interactions between the thermal zones.
- System combinations need further modelling work.
- The test of different controller types (zones, central, supervisory) needs also further modelling.

A second possibility to structure the zone part of the building model is to group models describing the same phenomena of all zones. Figure 4 shows this structure, which can be termed as "vertical". The layers represent here the different zone phenomena grouped for the whole building. One layer for example consists of the thermal zone models, another is an emitter system. This allows the addition of new phenomena into the building model without changing the rest of the model. This structure is used to integrate airflow modelling in the SIMBAD Toolbox.

The advantages of the vertical structure are:
- easy understanding and monitoring on the whole building level (e.g. water network)

- flexible combination of emitter systems (development of new control strategies) without further modelling effort
- high degree of flexibility for a controller test bench

The disadvantages are:

- Less comprehension of phenomena on the zone level graphically.
- Building model is, once developed, fixed to a maximum number of zones. The addition of new zones needs further modelling
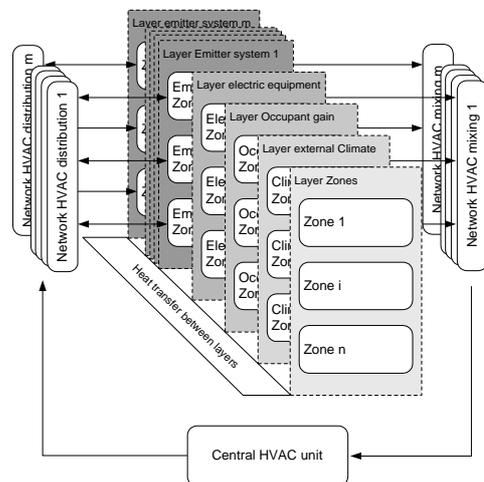

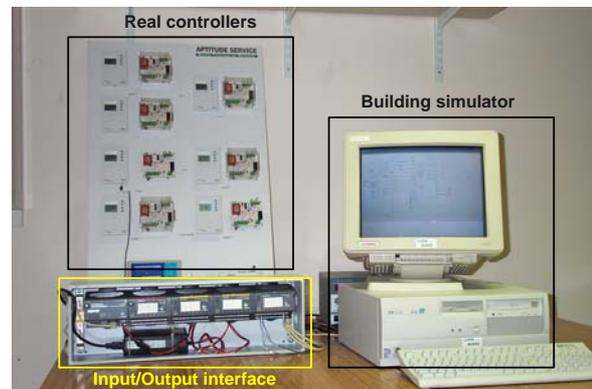Figure 4: Vertical structuring of a building model using system layers

Figure 5: Controller test bench for the QUALISIM project

The QUALISIM project follows this structure to represent an office building in 6 zones and the possibility to use different types of emitters connected to a real control system (central and zone control). The input/output interface between the real and virtual parts as shown in Figure 5 is a modular distributed data acquisition system that provides economical solutions for industrial monitoring and control applications. It can be connected to a PC computer by a RS 232 or Ethernet link. It offers a relatively cheap and flexible solutions for manufacturers to testdifferent control strategies implemented in real prototypes.

INTEGRATING AIRFLOW MODELS AND COUPLING WITH THERMAL MODELS

The simulation of airflow zone model is based on "Pressure Airflow Network" from Orme (1999). This model is used to calculate air flow rates into and out the zone and between adjacent zones. In this network, each zone is represented by one node and is connected to other zones by flow paths. The permeability model described in Villenave et al (1995) calculates the air infiltration rates.

Several types of air inlets [De Gids (1997), Jardinier et al (1990)] are integrated in the SIMBAD toolbox (Figure 6). Inlets can be active or passive. Active inlets can be connected to building management system. For passive inlets, it could be either uncontrolled, like crack, where the airflow rate through the inlet is variable and depends on external and internal air conditions (wind pressure, air temperature…) or self-controlled, like pressure controlled inlets where the airflow would be constant. Other components implemented are ducts, variable speed fan, static extractor, extract opening, T-joint. To integrate these models, the air vector of the SIMBAD toolbox had been modified to include information on CO_2 level, pollutants since these can be the controlled variables of some control strategies.
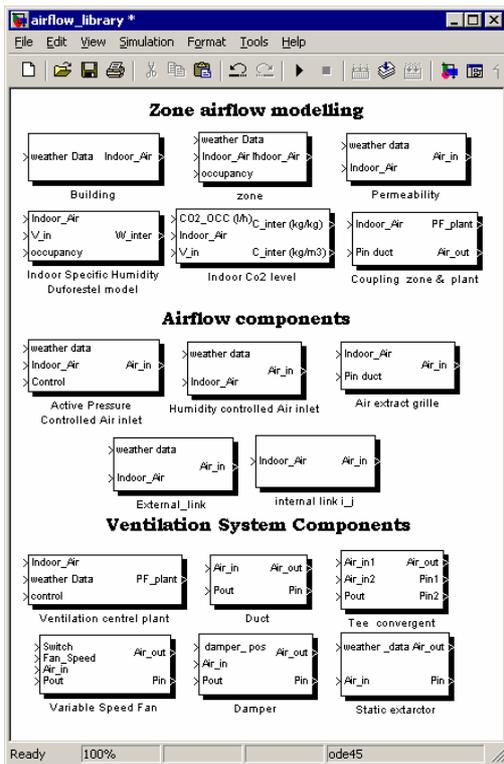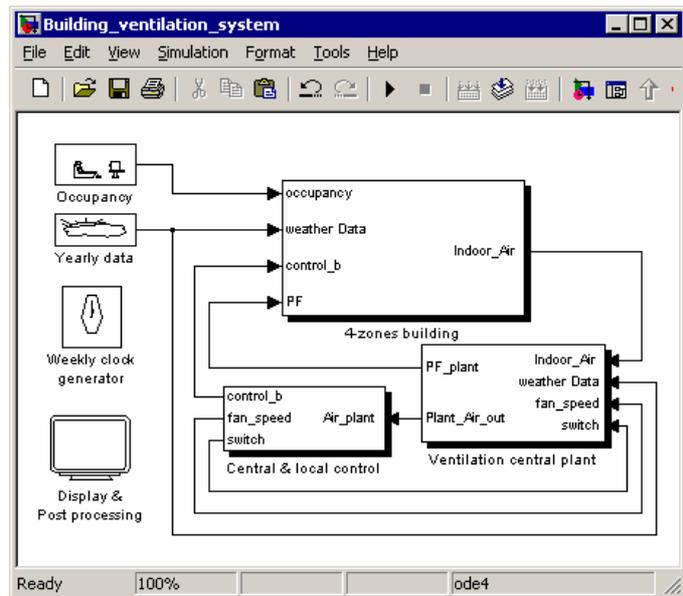
Figure 6: Airflow and systems models

Figure 7: Graphical representation of a ventilation system coupled to a building

The Simulink loop solver uses Newton's method with weak line search to solve algebraic equations. This method is very robust and avoid convergence problem due the choice of the initial condition. For the plant simulation, the equation loop or the inverse solver technique is used. The plant is simulated based on the fact that the algebraic sum of the pressure drops in any closed loop should be zero and in any junctions the air-mass balance should be maintained.

The models developed are compared to cases defined by Furbringer et al (1996) in the analytical evaluation of Comis. Walton (1989) defined a relatively complex network of airflow components involving 12 nodes and 20 fluid types of components arranged in series and in parallel with analytical solution. These comparisons are detailed in Jreijiry et al (2003).

Different methods have been proposed to couple an airflow model to thermal model [Kendrick (1993), Hensen (1995)] namely the sequential method, the "ping-pong" method or "onion" method and more recently the "full integration" as explained in Allard (1998). In Simulink, an algebraic loop occurs because the input of airflow model is driven by its output due a feedback path through thermal model. Simulink has algebraic loop solvers to resolve this situation iteratively with respect to the predefined convergence criteria using the "onion method". Thhe airflow and thermal models are implemented in the graphical environment in two layers or macro-blocks as described in (Figure 4). Figure 7 shows the graphical representation of a 4 zones building model with the central ventilation system.

CONCLUSION

This paper gives an overview of the development of a flexible test bench for design and test of control strategies of HVAC systems. The test bench is developed in Matlab/Simulink

environment that is currently used by the control industry and allows a detailed system monitoring of the whole system (access to all data transfers).

The laboratory is an interesting tool for companies since it can be used throughout the whole development phase. This means that control strategies can be tested by simulation and prototypes or available products can be tested by emulation. Furthermore, such a laboratory is flexible enough to allow implementation of new phenomena or systems in order to develop adapted control strategies.

Besides the SIMBAD Toolbox is being completed with airflow models so that coupled airflow and thermal simulations of a whole building with short time step can be achieved. It will thus be possible to build test benches for the development and test of ventilation control strategies, in particular to simulate the dynamics of the system and to evaluate the stability and robustness of control loops.

Future works will be focusing on using the new air flow models in whole building simulations to evaluate hybrid ventilation control strategies. This will be the first step prior to developing the laboratory with real prototypes of control systems and actuators.

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