

DEVELOPMENT AND QUALITY IMPROVEMENT OF HVAC CONTROL SYSTEMS IN VIRTUAL LABORATORIES

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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 informatic (hard-and software) for the development of Building Management Systems (BMS).

The necessity of innovation on this field imposes on the control industry 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 the correct function of the product under different conditions.

An adapted approach for this problem is the use of a virtual laboratory. It reduces also the necessary time for field tests that are long and expensive.

In this paper the advantages of this way to develop new products are shown. Two general structures of the virtual laboratory in the graphical simulation environment are compared adapted to the use for product development. These structures enable the user to study the control of different HVAC systems in buildings by simulation or by emulation.

INTRODUCTION

In an annex of the IEA, several research groups developed principles for the realisation virtual laboratories ([Annex17], [Haves98], [Karki94], [Laitila91], [Wang94], [Vaézi91]). [Vaézi97] shows possible applications of a virtual laboratory on the control field.

[Visi00] proposes a larger development and use of virtual laboratories on the HVAC field in order to permit faster and better development of controllers or systems.

The aim of this paper is the development of virtual laboratories (test bench) for the development and test of HVAC building controllers. Research laboratories as well as companies are possible users of this kind of laboratories.

Companies can use the laboratory throughout the whole development phase. This includes:

- completely simulated laboratory for the development of new control strategies
- partly simulated / real laboratory (emulation) for the test of prototypes or products

Research laboratories can use the test bench to study new control strategies or algorithms.

The test bench shall permit to implement new models of systems (e.g. other emitter types). At the same time it shall be possible without further difficulties to implement new, more detailed models of phenomena (e.g. more detailed blind model etc.). This shall help an ease development of new, adapted control strategies.

The test bench consists of three parts (Figure 1):

- virtual part (building simulation model)
- interconnection between virtual and real part (input/output interface)
- partly real/virtual part (controllers)

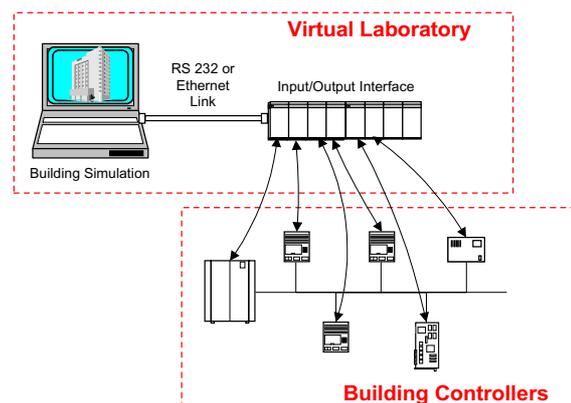


Figure 1: Scheme of a controller test using a virtual laboratory

The aim of this paper is to develop test benches in Matlab-Simulink environment [Sim98] and to show possible applications of the virtual laboratory.

The test benches are based on a library of models (SIMBAD Building and HVAC Toolbox) of HVAC components [Hus97]. The models available in this toolbox are structured using a methodology of modelling in a graphical simulation environment ([Hus99a] and [Hus99b]).

SIMBAD BUILDING AND HVAC TOOLBOX

The toolbox consists of a building zone model, models of heating, ventilating and air conditioning components, controllers of such equipment and various utilities (weather data files, occupancy profiles...) that are necessary to build up virtual systems to study the behaviour of HVAC plants.

All models are, before implemented into the library, either validated in real tests or in inter-model comparisons with existing models.

The toolbox benefits from the user friendliness of the Simulink graphical environment and uses the "drag and drop" method of the graphical environment to select the components required. The latter are linked together to build the systems.

One 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... These connection vectors enable the user to build the systems following the actual layout of the plant either on the air-circuit or water circuit.

Another important aspect of the models within the toolbox is that they use parameters that can be obtained from manufacturer's catalogues, data from certification bodies, norms...

To facilitate the use of the toolbox, the building zone model is provided with a list of predefined buildings. In fact, for control studies, the user need to verify that the control strategies or individual controllers are suitable to a class of buildings instead of one particular building.

CRITERIA FOR THE DEVELOPMENT OF A HVAC CONTROLLER TEST BENCH

➤ Various knowledge of the user

The user can have various knowledge of thermal building simulation. People with high or low knowledge shall both have the possibility to use the laboratory without limitations due to the models used.

In general, the models used are all simplified models using available parameters of the components. The test bench assemblage, modelled using these low-parameter models, shall be adapted for different users.

Simulation specialists on the one hand have a great flexibility in modelling and use of the bench since they have free access to all models. They have also the possibility to add new HVAC systems to the existing model.

On the other hand, an approach by typical and representative buildings and systems shall help users with lower experience to use the virtual laboratory by providing:

- predefined representative building or zone parameters (e.g. light-heavy inertia, small-large rooms)
- predefined representative parameters of current HVAC systems.

This test environment enables the user (mainly from the control field) to obtain representative results without a detailed knowledge of building modelling.

➤ Various controllers to be tested

The standard of HVAC systems and their controllers or control strategies is increasing quickly. The controllers of HVAC systems can be divided into three main groups:

- Local controllers (zone level)
- Controllers of central units (e.g. AHU)
- Supervisory building controllers

The developed test bench shall be able to test these three groups of controllers as a simulated version (algorithm or strategy) or as a real version (prototype or final product).

➤ Use of different HVAC systems

Typical HVAC systems as well as new combinations or innovative systems shall be available on the test bench:

- standard emitter systems
- combination of standard systems (e. g. convector and floor heating)
- new emitter systems (e.g. wall heating)

The structure of the simulated part of the bench shall permit change quickly from one HVAC system to another one and to add new components in order to test controllers for new HVAC systems or components.

➤ Choice of an adapted test bench structure

The developed criteria need to be taken into account simultaneously. The perfect test environment offers a free combination of systems, controllers and test methods. For example, when a new supervisory controller shall be developed, the other controllers can be simulated and vice-versa. The developed test bench shall thus provide as much flexibility as possible.

Figure 2 shows the principle structure of the test bench to develop:

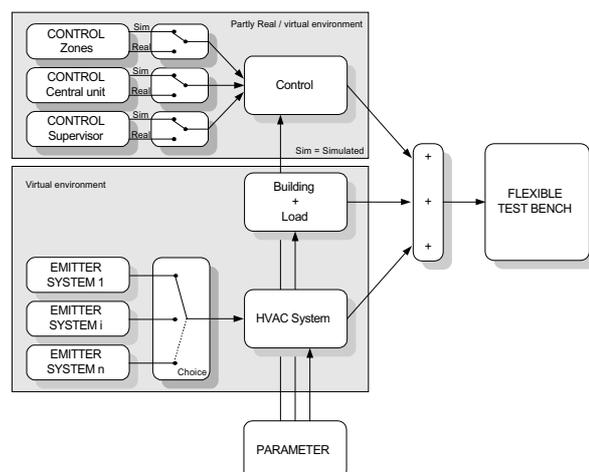


Figure 2: Structure of the controller test bench

In the upper block, the control block, it is possible, for each controller, to chose if the component shall be real or virtual. The lower block, the HVAC system, permits to chose or even to combine emitter systems. The building (thermal model of zones and of loads) is fixed regarding zone number. However, parameters of the building can be changed in order to carry out tests for different building types (load profiles, envelope structure, zone sizes, ...).

DEVELOPMENT OF THE VIRTUAL LABORATORY

The structure of the building model, used for the virtual laboratory, can generally be divided into the following groups:

- central HVAC system (e.g. AHU)
- Network HVAC distribution
- Network HVAC mixing
- Zones (including emitters and phenomena of heat, mass transfer or others in the zone)

The last group, the zone level can be structured in two different ways in Matlab-Simulink environment as shown in the following. Each of the two ways of structuring is characterised by advantages and disadvantages. They are shown in the following

➤ Structuring of the building model – two different approaches

□ The horizontal approach

To date, the SIMBAD controller test bench ([Vaézi97]) uses a modelling approach that structures the building by zones. [Hus00] developed a test bench for integrated controllers using this approach. Each zone includes an emitter system, load models (lighting, occupants, ...) and climate (depending on the orientation of the zone). The zone control is implemented in this structure. The structure of this building model can be called “horizontal” (Figure 3).

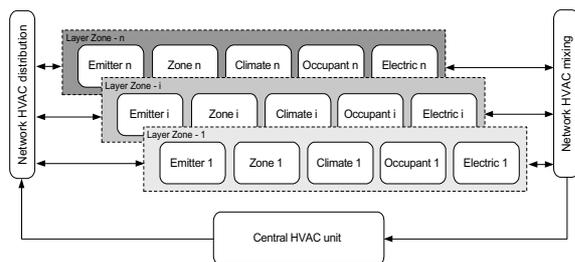


Figure 3: Horizontal structuring of the building model

The advantages of this structure are:

- All links between systems and the modelled phenomena on the zone level are easier to understand and to monitor.
- The structuring permits the development of new control strategies on the zone level.
- It is easy to add new zones to a building model.

The disadvantages are:

- For a building model, this structure is not flexible enough to implement new models on the zone level.
- System combinations, as specified in Figure 2, need further modelling work.
- The test of different controller types (zones, central, supervisory) needs also further modelling.

[Hus00] developed a simulator to test integrated control strategies between HVAC system, lighting and blind applications within a zone. The simulator is easily modified to test real controllers by removing the corresponding block representing the virtual controller. The scheme of one zone based on horizontal structuring is shown Figure 4:

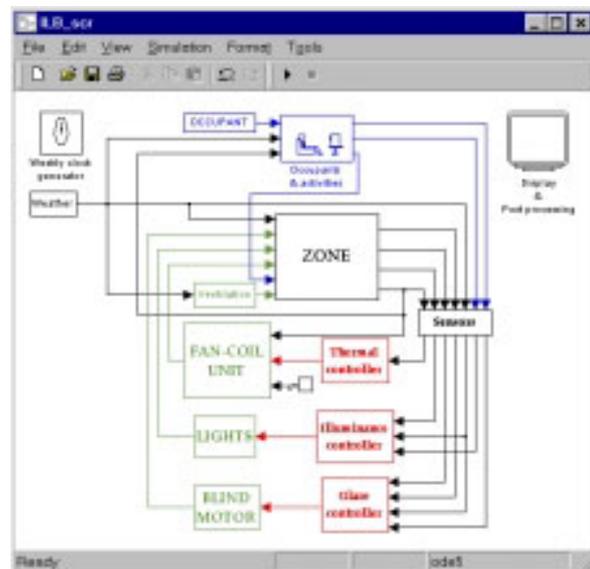


Figure 4: Horizontal structuring of the building model

□ The vertical approach

A second possibility to structure the zone part of the building model is to group models describing the same phenomena (e.g. radiation model) of all zones. The structure can be called vertical, corresponding to Figure 5. The layers represent here the different zone phenomena grouped for the whole building. One layer for example consists in the thermal zone models, another in an emitter system. This permits to add models describing phenomena that have previously been neglected into the building model without changing the rest of the model. It is, for example, possible to implement layers of different emitter systems that can be chosen or even combined.

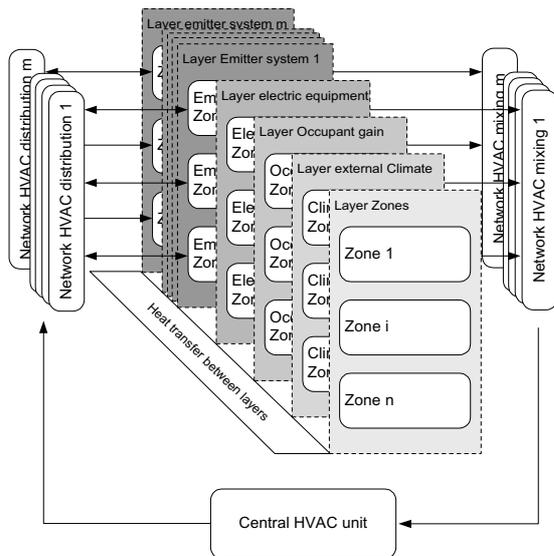


Figure 5: Vertical structuring of a building model using system layers

The advantages of the vertical structure are:

- easy understanding and monitoring on the building level
- flexible combination of emitter systems (development of new control strategies) without further modelling effort
- high degree of flexibility for a controller test bench
- easy monitoring (e.g. Water network)

The disadvantages are:

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

As shown in Figure 2 the test bench shall permit to have the highest flexibility on the building level. The vertical structure is chosen for the development of a new test bench [Vaézi00] since it is more adapted to this problem. The development of the vertical structure permits also the direct comparison of the advantages and disadvantages of both approaches since the horizontal structure is already used in actual versions of virtual laboratories [Vaézi97].

Figure 6 shows the main parameters of the test bench defining the test bench structure.

The user can construct his test bench by these parameters. He has to select:

- Number of zones
- Emitter system (possibility of combinations)
- Load models (lighting, occupancy and solar)
- The controller to be tested by emulation

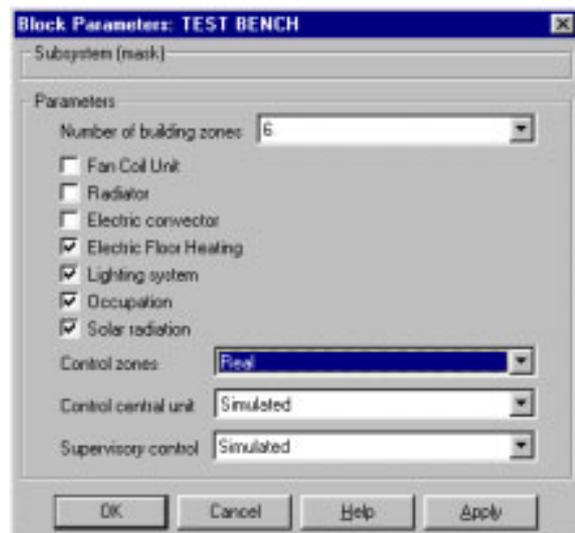


Figure 6: Parameters specifying the test bench

Following these selections the user is asked to parameter the selected systems (zone type, emitters, loads, ...). He has the possibility to:

- chose between predefined systems
- input all necessary data on a main menu
- input all necessary data in the Simulink environment (block masks)

The first two choices are designated for users of lower knowledge of thermal modelling, the third choice for specialists.

The test bench is structured in the same way as shown in Figure 5. Two blocks are added, the block “building control” and a block “electricity meter”(Figure 7).

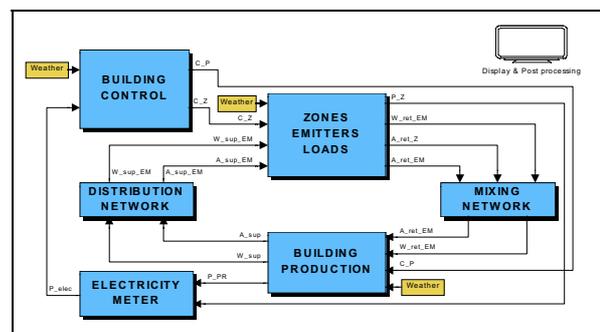


Figure 7: General structure of the test bench

The building model contains the following parts:

- Building control (zone control, central HVAC unit control, supervisory control),
- Building production (Air and water preparation for building HVAC system, e.g. AHU),
- Distribution of water and air flows from “production”,
- Mixing of water and air flows returning from emitters and zones to the central unit,
- The layer models “Zones Emitters Loads” (Figure 5),

- Electricity meter (building electricity consumption)

The layers, modelling the phenomena in the building zones, are divided (Figure 8) into:

- Emitters
- Loads (lighting, occupants, solar)
- Thermal phenomena zone (air and envelope)

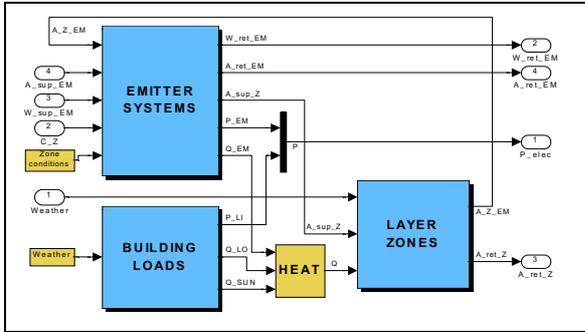


Figure 8: Structure of the block “Zones Emitters Loads” in Simulink

The vertical structuring (layers) of the models in the building is shown for the example of the layer “zones” (Figure 9).

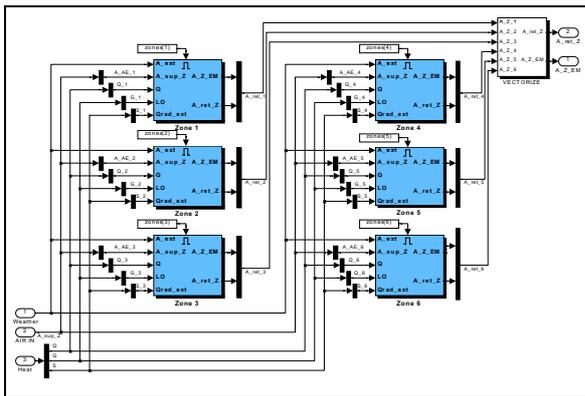


Figure 9: Modelling of layer “zones” in Simulink

The inputs into the particular zone models (down left in Figure 9) correspond to the inputs into the complete layer “zones” except that the input into the layer is a vector containing all the inputs into the particular model. The scheme, developed for one zone, can thus be used for the building model. In each layer, the input vector is then distributed to the several zones. This permits to have a building with variable zone number. Following the specified zone number the number of simulated zones is automatically changed.

In all other layers of models of zone phenomena the same structure is used. It is thus easy to understand the modelling or to modify the model.

Another principle is applied in the model development simplifying the understanding of the building model: Heat flows, mass flows and controller commands on the one hand are represented as vectors in the model

([Hus99]). States as for example temperature, humidity or pressure in the zones on the other hand are not represented as vectors since they do not correspond to real “flow”. They are stocked to a “global” basis of variables where all states are available for all models. Figure 8 for example uses this principle in the block “Zone conditions”. The input into the model of the emitters is taken from the global data basis. In this way the complexity of interconnections in the building model is kept as low as possible.

In the block “Building control” (Figure 7), the simulated and the real controllers are implemented. The Controllers are divided into:

- Supervisory controllers
- Central HVAC controllers
- Zone controllers

In each of these controller blocks one the real or virtual controller can be chosen.

The model runs for all cases using simulated controllers. If the user wants to carry out tests by emulation, the real controller to be tested has to be connected via the data acquisition system (real-virtual and virtual-real). The inputs and outputs that are necessary for the controllers have to be specified in a separate file in C++ language and to be compiled.

In a second step, several test benches (different zone numbers) are compiled via the “real time workshop”. This application has the advantage that it can be used without using Matlab-Simulink environment.

INTERCONNECTION BETWEEN REAL AND VIRTUAL PART (INPUT/OUTPUT INTERFACE)

To be compatible with the software flexibility, the input/output interface is a modular distributed data acquisition and control 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. These two features offer the user:

- The easy extension and configuration of hardware architecture (modules can be easily changed or added to fit the bench to BMS configuration),
- The fast and comfortable maintenance (the modules are connected via a bus, they can thus be changed easily),
- The connection to a stationary as well as laptop computer to realise a portable bench for in site testing.

Figure 10 shows a test bench realised in the QUALISIM project. The input output interface is placed left down on the picture.

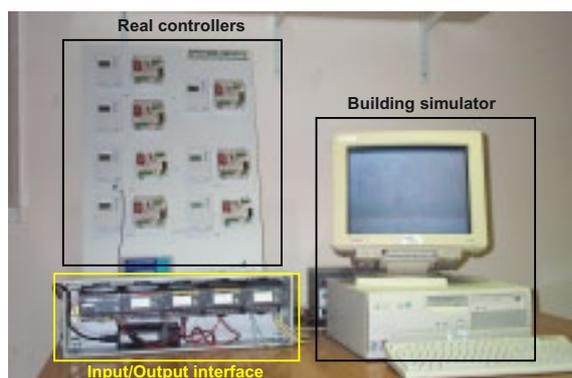


Figure 10: Controller test bench for the QUALISIM project

The detailed specifications of the input/output interface are listed in [Vaézi00].

ACTUAL APPLICATION

In the French research project “QUALISIM” the test bench is used for tests of several controllers by emulation. The controllers to be tested are zone controllers as well as supervisory controllers. The systems to be tested use mostly electricity as energy sources except the fan coil unit that is used as a two-pipe/two-wire combination.

The aim of the project is, for standard systems as for example the electric convector, to test the existing controllers. For non-standard systems as for example the combination of the emitter systems convector and floor heating, controllers shall be developed and then be tested in the virtual laboratory. The developed vertical structure is very helpful for this step.

The following configurations shall be tested within the project:

Table 1: Controller tests in the QUALISIM project

Case	Type	Zones	System
1	Office	6	- Electric convector - Fan coil unit - Electric floor heating
2	Office	1	- Electric convector - Fan coil unit - Heated floor - Chilled ceiling
3	Flat	3	- Electric convector - Floor heating
4	Pavilion	3	- Electric convector

Since the used emitters are mainly electric, no coupling of energy supply in the building is integrated in the whole building model.

APPLICATIONS IN PROGRESS

To date, except the fan coil application, no coupling of fluid flow in the building system is considered in the building models. A model, coupling all water and airflow on plant and zone level, of a building with a complete VAV system is in progress and will soon be used for tests. This building model shall also be able to simulate a flexible zone number without a re-dimensioning (due to changed load for the plant) of all models on the plant level. A more detailed zone model ([Riederer01]) is also implemented in this building model.

CONCLUSION

In this paper the development of a flexible test bench for building controllers is shown. The test bench is developed in Matlab-Simulink environment that has the following advantages:

- The environment is currently used by the control industry
- The Simulink environment allows a detailed system monitoring of the whole system (access to all data transfers)

The developed test bench permits an easy adaptation to new configurations (other zone number, different systems, ...) and to change from simulation to emulation without any modelling work. Zone controllers, central HVAC controllers and supervisory controllers can be tested.

A general structure of the virtual laboratory is developed adapted to the use for product development. In the laboratory, the user has only to select a HVAC system in a predefined list of systems.

The users can be research laboratories as well as companies due to different methods of parametering.

For companies the laboratory is an interesting tool since they can use it throughout the whole development phase. This means that control strategies or controller parameters can be tested by simulation and prototypes or available controllers can be tested by emulation.

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