REAL TIME SIMULATION OF A BUILDING WITH ELECTRICAL HEATING SYSTEM OR FAN COIL AIR CONDITIONING SYSTEM

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Abstract : An office building with electrical and fan coil heating system is designed to test Building Management System (BMS). This tool called SIMBAD (SIMulator of Building And technical Devices) is used in order to realise performance monitoring control tests. The building consists of 6 zones and is equipped with electrical convectors or fan coils.

INTRODUCTION

Since 1990, the CSTB has begun developing digital building and services simulators to test Building Management Systems (BMS) and stand-alone heating/air conditioning controllers. These studies began within the scope of an international co-operation with different European and American teams participating in Annexe 17 of the International Energy Agency (IEA). On completion of these works, the CSTB constructed the first version of its digital simulator : SIMBAD (SIMulator of Building And technical Devices).

The first version of the simulator, SIMBAD 1.0, was installed on a Unix work station. Using this version, the CSTB constructed a functional testing and evaluation tool for BMS used for heating/air conditioning installations and adaptive control systems.

However, the user interface on version 1.0 of the SIMBAD simulator was not particularly user-friendly and the computer environment (Unix on a work station) made the tool relatively expensive to develop and maintain.

In 1992, a subsequent version of the simulator, SIMBAD 2.0, was installed on PC-MS DOS type equipment. This led to a SIMBAD version with a low equipment cost but whose software development and user interface continued to be fairly impractical.

In 1994, with the co-operation of Electricité De France (EDF), the CSTB created SIMBAD 3.0, its first simulator to work in a PC-Windows environment. This version uses both low cost equipment and a user-friendly simulation environment aimed at users unfamiliar with simulation systems.

The simulator developed within this framework allows the testing of BMS for use in buildings with electric powered heating and air conditioning : convectors or two 2 pipes fan coil with changeover and electric heaters.

To date, and using the SIMBAD simulator, ten BMS manufactured by different manufacturers have been tested. Amongst these BMS, five have been subject to evaluation reports. Syntheses of these reports have been published and are available to professionals in the building sector (managers, operators, installers, etc.).

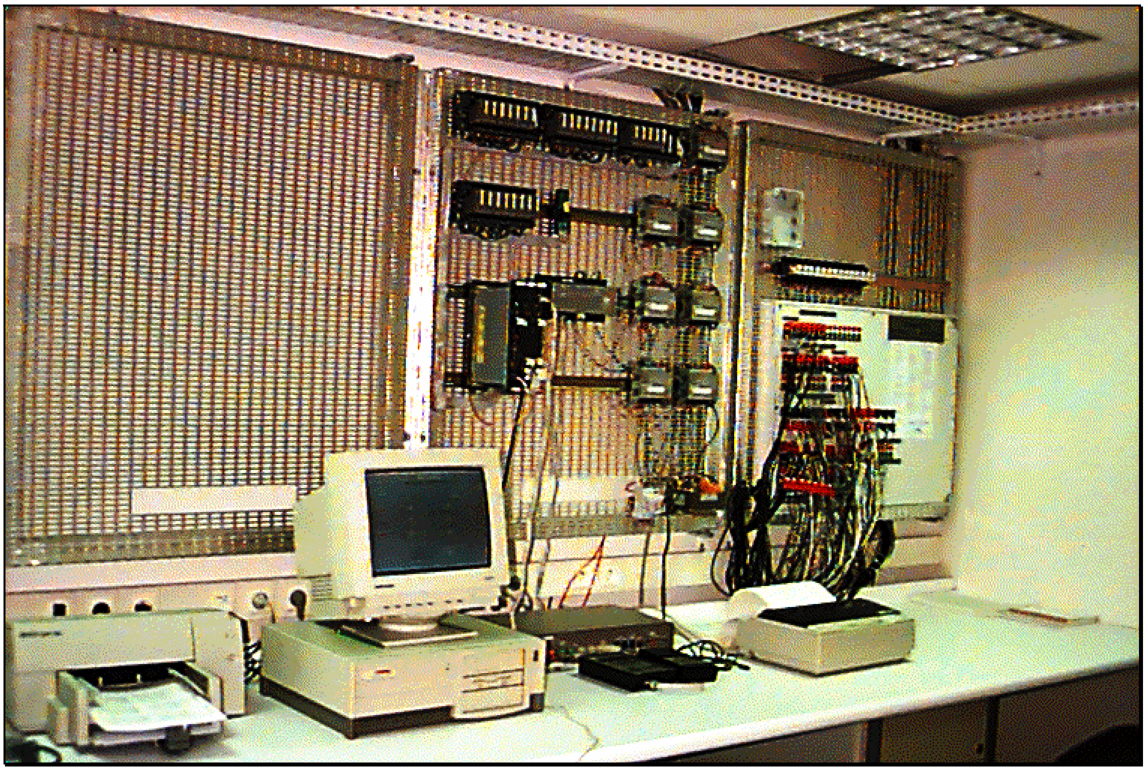

Figure n°1 : Photo of a BMS connected to SIMBAD

LIKE A FLIGHT SIMULATOR

SIMBAD can be compared to a flight simulator used to train pilots or test new equipment to be installed in a plane. Consequently, and similarly to the way that a flight simulator is used to simulate the behaviour of a plane and is operated by a pilot or controller (automatic pilot), the building and its climatic services are simulated by SIMBAD and are operated by a controller (BMS, controllers, automatic systems, etc.).

The SIMBAD simulator includes both software and hardware elements:

- The software permits simulations of different types of buildings with their heating/air conditioning equipment. It includes a simulation environment (MATLAB/SIMULINK manufactured by MathWorks Inc.), building and climatic equipment models, typical installations with different operating states (in normal mode and in the presence of faults) and climatic and internal load files.

- The hardware permits dialogue with the control system to be tested. It includes the acquisition/control card to be placed in the PC (for a restricted, low cost version) or an acquisition and control processor located outside the PC (for a version with a large number of points).

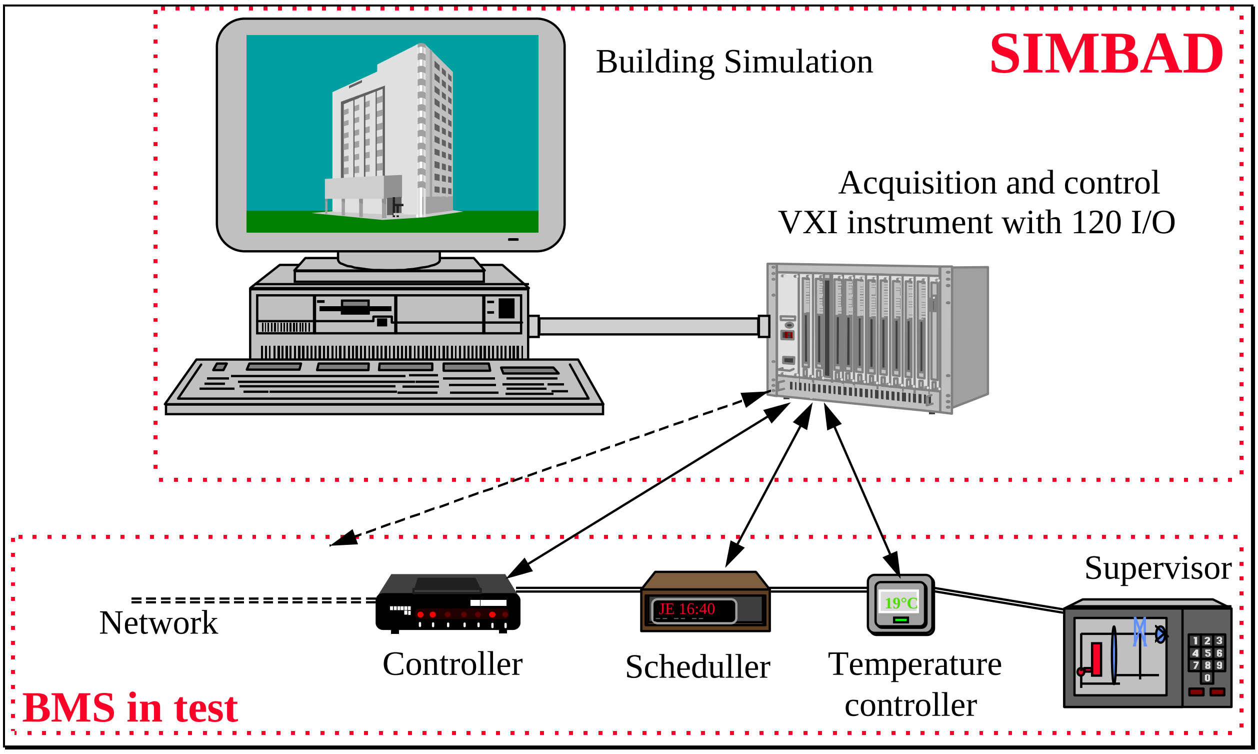

Figure n°2 : Diagram of the SIMBAD simulator

A MORE USER-FRIENDLY 3.0 VERSION

To test the building management controllers or systems used in the building, there is a need to have different types of buildings, heating/air conditioning installations and meteorological and occupation scenarios.

To create these installations, the CSTB has developed libraries of basic equipment models: heating/cooling coils, hot/cold units, pump, convector, etc.

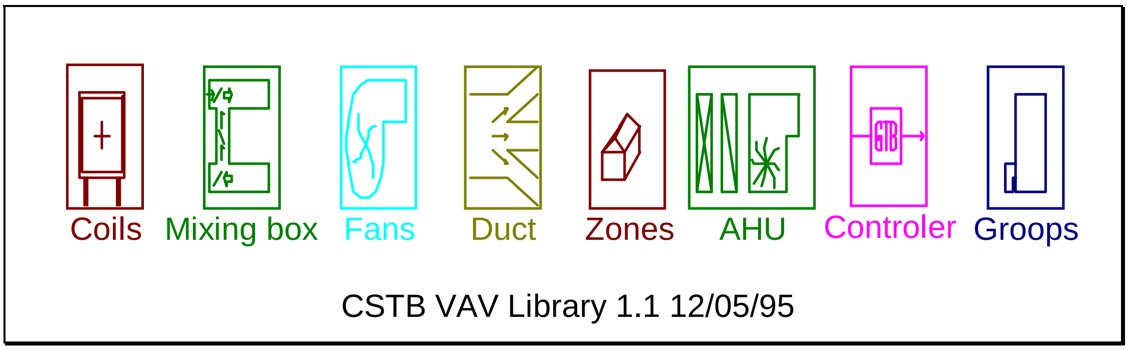

Figure n°3 : An example of a library of buildings and air conditioning equipment

MODELLING CONSTRAINTS

To create models from our simulation, we adopted a certain number of modelling constraints to allow us to test the BMS (control systems) on an entire building (complexity) :

- modelling aimed at systems (equipment included in an air conditioning installation) with vectorization of the physical input/output magnitudes (example: the air in a ventilation duct is represented by a temperature, humidity, pressure and flow rate),
- use of dynamic models for the building and its services, if possible in a simplified form,
- use of a detailed model including non-linearities for the control units (example: cold valve on the fan coil unit),
- use of a precise model for the measurement units (sensors and Green and Yellow electricity meters - two different french electricity rates).

The models representing each elementary unit in this hierarchical structure are standard thermal models of the building, detailed non-linear models for the control units and, finally, detailed models for the sensors.

CREATION OF A SIMULATED INSTALLATION

To provide heating/air conditioning installations, the elementary equipment units must be interlinked to construct the building and its services. Once these connections are made, all the elements must be dimensioned, in other words the value of the model parameters must be defined through simulation.

The three largest installations developed with SIMBAD are :

- a 2,000 m², five storey office building with a hot water heating installation using steel radiators with thermostatic valves,
- a 18,000 m² office building separated into three zones, with a Variable Air Volume (VAV) air conditioning installation,
- a 2,000 m², five storey office building with 2 possible options, being either a direct convector type electric heating installation or an air conditioning installation using 2 pipes fan coil with changeover and electric heaters.

This document particularly examines the installation of the 2 pipes fan coil (with changeover and electric heaters) unit type air conditioning system.

The building chosen for this study corresponds to a representative construction in the office building sector. It is a five storey building (ground floor + 4 upper floors) lying over a basement carpark. It has a central reinforced concrete core, and posts and beams supporting heavy slabs. The facades use curtain walling with opaque breast walls.

The building represents a heated surface area of 1,475 m² (in all, the building covers 2,000 m²) with a habitable volume of 3,834 m3 (with a total of 5,200 m3). The G-value is 0.52 W/m3.°C.

The building is either heated by electric convectors placed on the breast walls or air conditioned using 2 pipes fan coil with changeover and electric heaters.

In the case of a building heated by electric convectors, the air renewal in the offices is provided by a simple Exhaust Mechanical Ventilation (EMV).

In the case of a building air conditioned by 2 reversible tube/2 wire fan coil units, an air handling unit (AHU) using all fresh air provides air at between 19°C and 24°C depending on external conditions.

Office lighting is by fluorescent tubes.

The building has an entirely electric kitchen able to provide up to 300 meals.

The Hot Water Production (HWP) is provided by a 1,500 litre hot water tank.

The electric equipment includes:

- the convectors or fan coil units,
- the EMV or AHU,
- the lighting equipment,
- the office systems (computers, printers, photocopiers, etc.),
- the kitchen equipment,
- a HWP tank.

DESCRIPTION OF THE BMS FUNCTIONS

In the case of a 2 pipes fan coil (with changeover and electric heaters) unit type heating/air conditioning installation, the BMS controls :

- the terminal fan coil unit controls,
- the power limitation,
- the optimisation of intermittency per zone,
- the starting up of the AHU,
- the HW production,
- the lighting programming,
- the air conditioning, AHU, HWP and lighting overrides,
- the power cut-off and electricity contract.

To test these functions, we asked the BMS constructor to configure and install his equipment on the SIMBAD simulator in accordance with detailed specifications. Following a period of adjustments during which the constructor adapted his functions, an installation handover report was signed prior to the beginning of the tests.

DESCRIPTION OF THE SIMULATION

The simulation is composed of different elementary models. Each elementary model have been validated with real measurements comparison and the whole simulation is validated with energy conservation analysis.

The method we use for the numerical integration of ordinary differential equations of the simulations is Range-Kutta orders 4-5. The maximum time step of the simulation is 5 seconds and the duration from 8 hours to 15 days (in real time). During the simulation we store about 55 variables (inputs/outputs of different models) with a time step of 5 seconds. This huge quantity of data is treated after each test to obtain specific parameters or graphics which are necessary to assess the control equipment under test.

For reasons of simplicity and to structure the simulation, the entire installation was subdivided into 5 major groups. These groups are briefly described below.

The ELECTRICAL BOX includes circuit breakers and relays for the electric installation.

The BUILDING includes models of the building skin, heat emitters, ventilation, kitchen, HW production, lighting and solar loads.

The METER includes the models of the electric power distribution meters and the building's general meter.

The BMS includes the model of the dialogue interface with the management equipment to be tested.

The COLD UNIT includes the chilled water production model for a fan coil unit installation.

In addition to these 5 groups, there are 5 other groups that simulate the building's environment.

The CLOCK includes the model of a clock and a weekly calendar.

The METEO includes a model of the changes in the outside temperature (live file).

The OCCUPATION includes the zone occupation models.

The SCENARIO includes scenarios for actions resulting from occupants opening and closing windows, as well as for overriding the heating, lighting and HWP.

The BREAKDOWN includes breakdown appearance models for the different technical equipment elements to be found in the building.

The installation, as created in a simulated environment, is represented below.

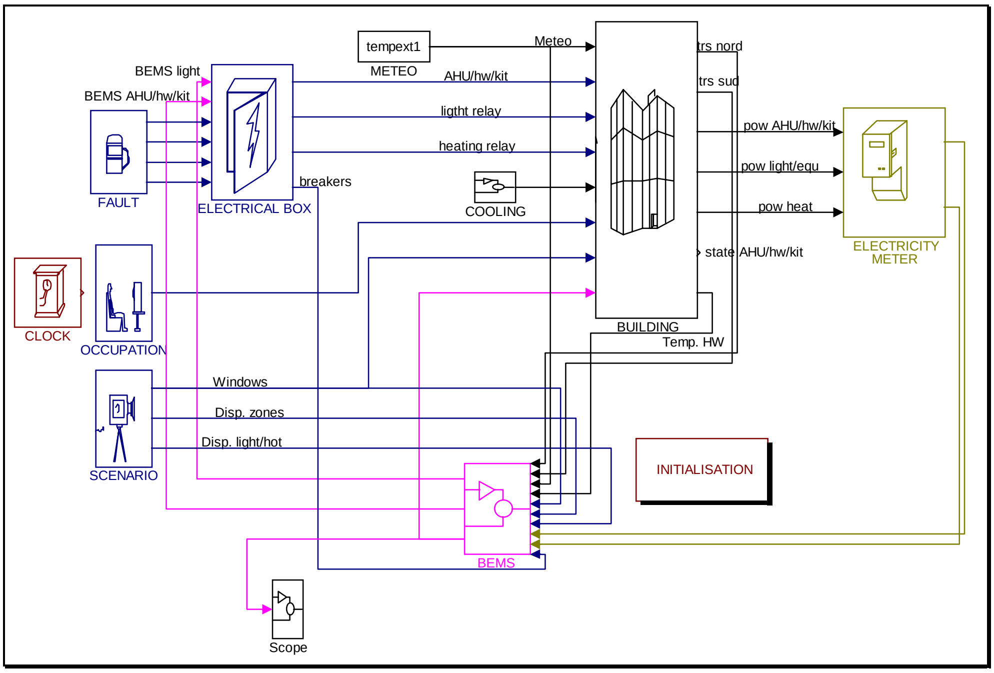

Figure n°4: The modules are interlinked to create the simulated building.

Each module is itself made up from units or other modules.

We shall not present a successive description of each of these main groups. However, to illustrate our subject, we shall describe the most important group: the building.

DESCRIPTION OF THE BUILDING

The building was broken down into 6 thermally homogenous zones (see figure 4): 3 north zones and 3 south zones. This breakdown is sufficiently representative of the real situation. It means that the sunlight levels (north and south zones) and the building's thermal disparities (floor level below roof, intermediate floor levels, floor level in contact with non-heated rooms) can be taken into account.

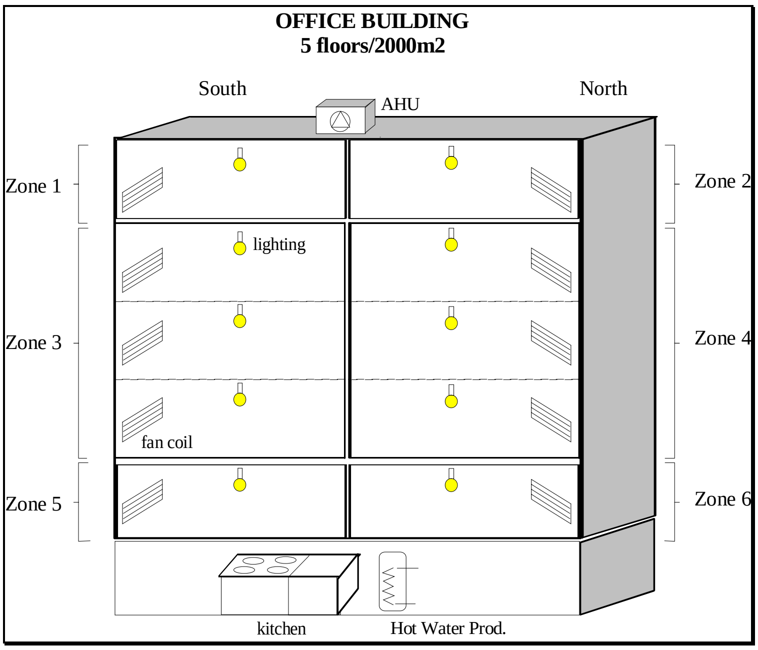

Figure n°5: Vertical section through the building with breakdown into 6 thermal zones

The BUILDING unit in the simulation is broken down into 5 sub-units :

- the north part of the building: the *north zones* unit
- the south part of the building: the *south zones* unit
- the HWP tank: the *HWP* unit
- the kitchen: the *kitchen* unit
- the EMV or AHU: the *AHU* unit.

The BUILDING unit is presented in the same way that it is constructed in the simulation environment.

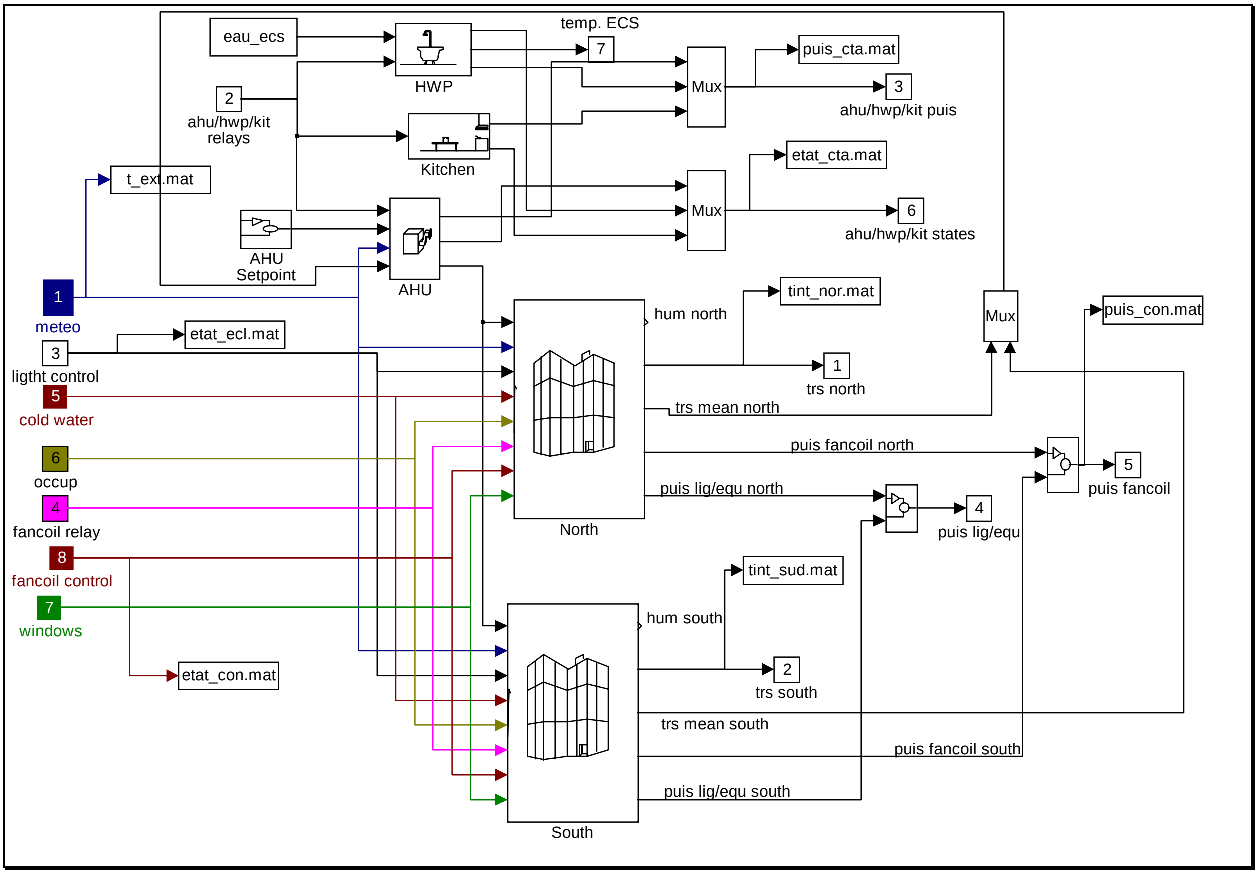

Figure n°6: The BUILDING unit in the simulation

From the units describing each of the building's facades (*North* and *South*), it is possible to access the different building zones. Below, we have described the *Zone 2* unit.

DESCRIPTION OF THE ZONE 2 UNIT

The *Zone 2* unit is broken down into 4 sub-units :

- the envelope model for a zone: the *Bat mono* unit,
- the humidity calculation model for a zone (not used when heating): the *Humidity* unit,
- the electric convector or 2 pipes fan coil with changeover and electric heaters model: the *Convector* or *Fan coil* unit,
- the calculation model for the calorific power injected and extracted from the zone: the *Power* unit.

The ZONE 2 unit is presented in the same way that it is constructed in the simulation environment.

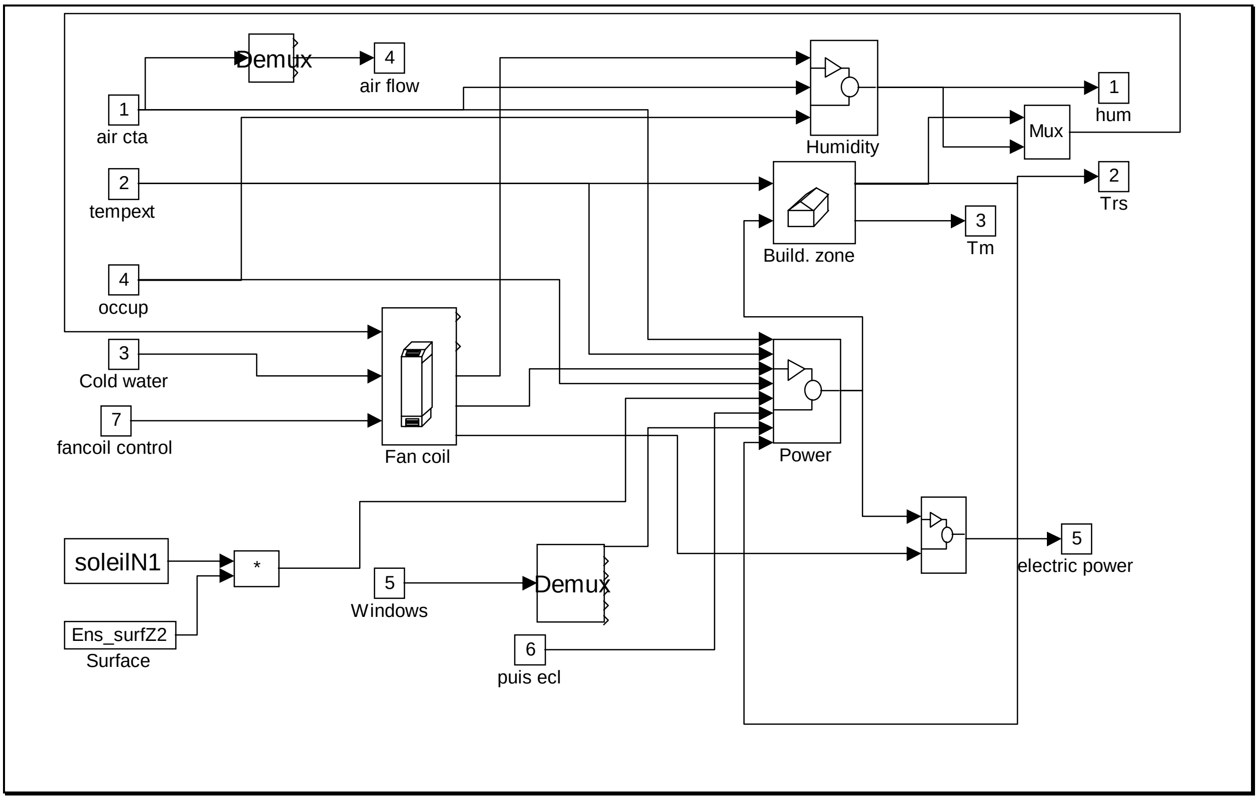

Figure n°7: The ZONE 2 unit in the simulation

A FEW RESULTS

Below, we have represented the test results of 2 BMS: BMS X and BMS Y.

BMS X acts on a building that is air conditioned by fan coil units and ventilated by an AHU.

BMS Y acts on a building that is heated by convectors and ventilated by EMV.

In both cases and for the purposes of our tests, we presented the temperature within a building zone and the calls for electric power by all the fan coil units (BMS X) or convectors (BMS Y) during a winter day.

As can be seen on the curves presented in figures n°8 (BMS X) and n°9 (BMS Y), the following function behaviours can be seen with the tested BMS :

- the intermittency optimiser which starts up the heating to attain the occupancy set point (19°C) at 8h00 in the zone and which switches to a non-occupancy set point (12°C) at 18h00,

- the room temperature adjustment which stops the heating in the zone as from the moment that the internal temperature exceeds the occupation set point,

- the power limitation which is triggered as soon as the occupation set point is attained in the zone (activation of this function during the starting up means that this set point cannot be attained during the occupation period).

In the test with BMS X, the internal loads and the AHU were sufficient during occupation hours for the building's heating needs. This, however, was not the case with the BMS Y test where the building received the same internal loads but was only equipped with EMV.

The constructor of BMS X used a starting up optimisation function which led to minimising the power consumption but not the cost of the power. As a result, the majority of the heating power was consumed during day rate periods (after 6h00) when power is relatively expensive.

The constructor of BMS Y used a starting up optimisation function which led to a lowered electric heating cost. As a result, most of the electric heating power was consumed prior to day rate periods (off-rate hours prior to 6h00) when this power source is relatively inexpensive.

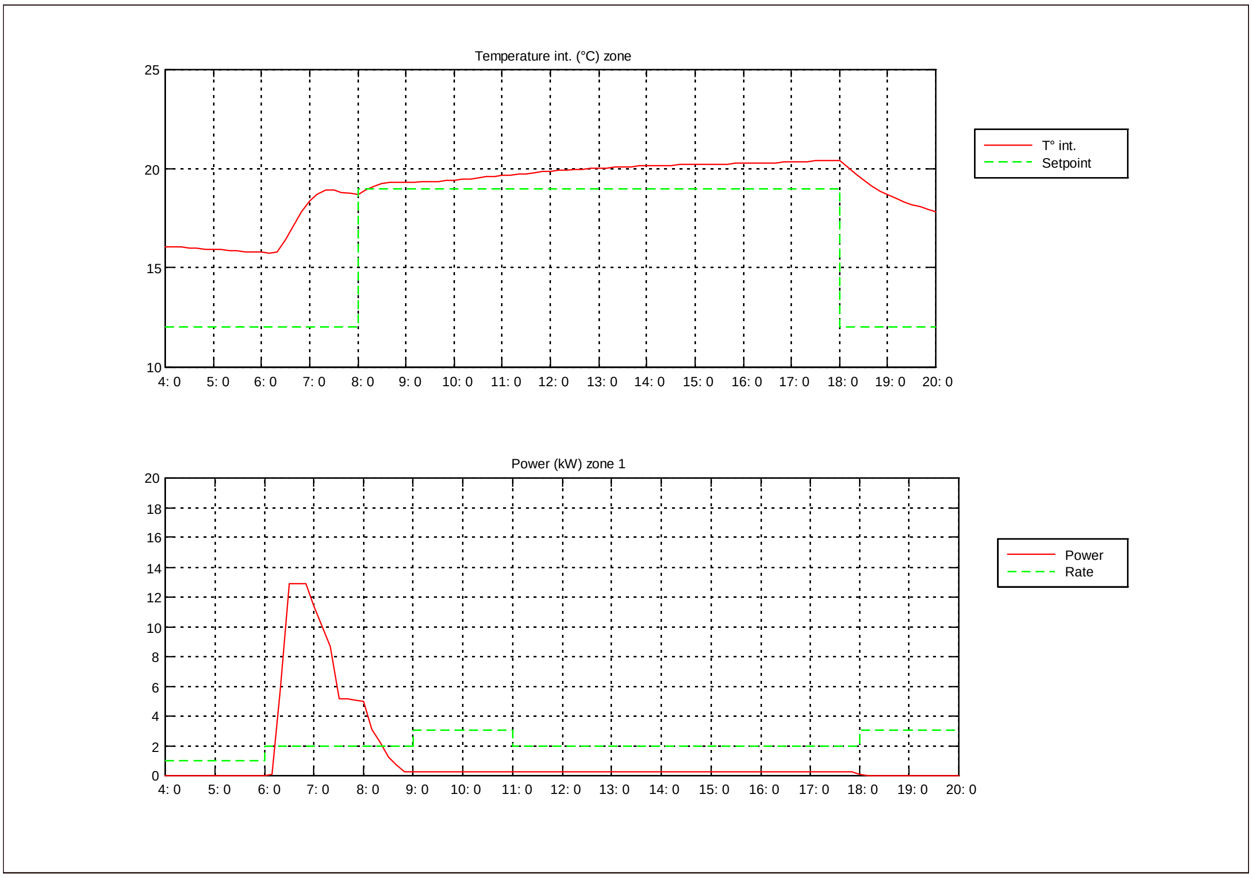

Figure n°8: Result curves for BMS X, installed in a building air conditioned by fan coil units and ventilated by an AHU

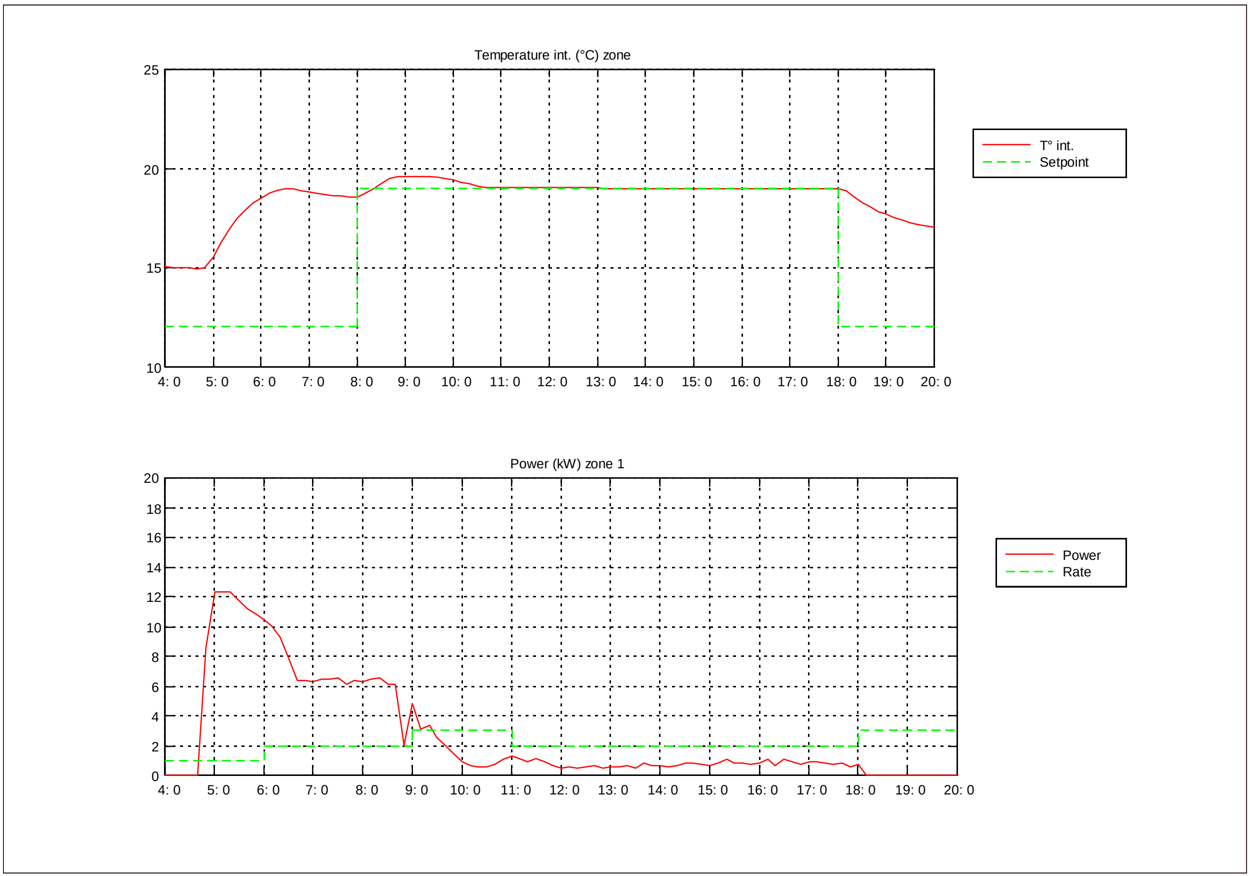

Figure n°9 : Result curves for BMS Y, installed in a building heated by convectors and ventilated by EMV

OTHER POTENTIAL USES

The SIMBAD tool is currently being used to evaluate the performance levels of Building Management Systems or heating/air conditioning installation controllers, the SIMBAD tool could find new uses. The development of new equipment models and a new simulation environment that is easier to use and operates using inexpensive machines (PC) means that it is possible to envisage using an adapted SIMBAD for uses other than those covered by the test, such as a training and development aid tool for the control system industry.

The simulator could provide a large number of cases of buildings with their specific heating/air conditioning installations (different situations and installations) linked to BMS to train management agents in how the system can be used and regulated. It would also allow industrial companies to test new control-command strategies in all possible situations: different external and internal building conditions scenarios, fault or equipment breakdown simulations, etc.

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