SIMUBEMS: An educational tool on control techniques

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ABSTRACT

This paper describes an educational tool developed at LASH ENTPE (France) laboratory. The objective of this tool, called SIMUBEMS, is to familiarize ENTPE students with control techniques and allows performing simulations in order to test heating and ventilation control strategies.

An office building equipped with an HVAC system has been used to carry out the simulations. The modelled zone is 9 m long, 6 m large and 2.5 m height and has large glazed façade. SIMUBEMS has been developed under LABVIEW environment and is based on an explicit finite differences method. Several control strategies for heating (On-Off and PID) based on temperature have been implemented to the model.

The objective of the simulations conducted by students is to identify optimal parameters for each controller in order to reach a good thermal comfort at the least energy cost. The simulations aim also at highlighting the key role of advanced control techniques to manage heating systems.

KEYWORDS

Education, Training, Comfort, Energy efficiency, Control, BEMS

INTRODUCTION

Building Energy Management Systems (BEMS) are reliable and flexible systems that take advantage of hardware and software technology. They allow the system operator to monitor and control building services such as heating, ventilating and lighting. The principle of BEMS consists in collecting information on the building (temperature, pressure, water level, valve position) and making decision on when and how to operate energy consuming systems in an efficient manner. Such systems can reduce significantly energy consumption while maintaining good indoor conditions in terms of thermal comfort, indoor air quality, lighting and acoustic comfort, Levermore (2000).

Recent studies have shown that energy management is considered essential by building owners but its implementation is far from optimum. Many building owners who are willing to implement Building Energy Management Systems in their own buildings express a lack of information and tools. Thus, we have developed an interactive tool called SIMUBEMS in order to offer valuable information for a better understanding of Building Energy Management Systems capabilities. The development of SIMUBEMS tool has been initiated within the framework of the MEDIABEMS project (European program SAVE I), Michel et al (1998). This project

aimed to assist building contractors in selecting appropriate systems for their specific needs. The audience targeted by the software developed is architects, engineers, students, teachers, building managers planners and any other professional involved in the building design. SIMUBEMS is actually used to familiarize ENTPE student with control techniques and allows performing simulations in order to test heating and ventilation control strategies.

GENERAL DESCRIPTION

SIMUBEMS is an interactive tool that incorporates a dynamic model of a multizone building with a heating network based on radiators supplied with hot water produced in a boiler. Each zone is ventilated by a pre-heated air at a constant set-point around 18°C. The building characteristics (geometry, materials, HVAC systems) cannot be modified. However, the user can select the climate for simulations, occupancy schedules temperature set-point and controller.
Simulations consist in running this model for a full week (but it can be stopped at any time) and the user will be offered the possibility to monitor various types of parameters and possibly modify manually some of them during the simulation. This tool also offers the possibility to display and to save information and history of each simulation. Figure 1 shows the main window through which the user can access the different possibilities of SIMUBEMS.

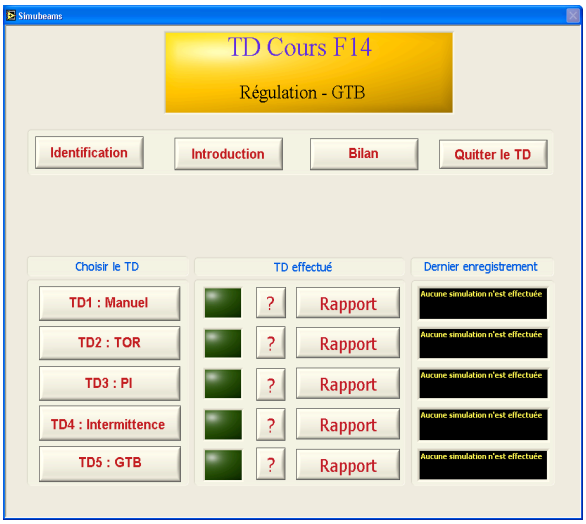

Figure 1: The main window of SIMUBEMS

This window provides general information on BEMS supervisor interface use and specific information on the software. At this level, the user can also choose the control strategy and preview the energy saving or the comfort assessment. Various possibilities of previewing and saving are also proposed.

Building

The building for which simulations are performed in this software is a residential building with 4 zones. Table 1 presents the characteristics of each zone. None of the building's characteristics can be modified and they are displayed for information only.

Table 1
Building characteristics

Zone	Area [m²]	Height [m]	Window area [m²]	Air flow [m3/h]
Zone 1	54 m²	2.5 m	13.5 m²	250 m^3/h
Zone 2	48 m²	2.5 m	8 m²	250 m^3/h
Zone 3	36 m²	2.5 m	13.5 m²	125 m^3/h
Zone 4	32 m²	2.5 m	8 m²	125 m^3/h

In order to reduce the simulation time and thus allow the ENTPE students to perform a maximum number of simulations, only Zone 1 is taken into account.

Heating systems

A boiler heats the water supplying radiators in all zones as well as the water supplied to the heating coil in an Air Handling Unit. Fuel is supposed to be the energy used in the boiler and energy consumptions are therefore defined in litres of fuel. However, equivalences are given with electrity in kWh.
The water set point temperature is a function of outdoor temperature as follows (figure 2):

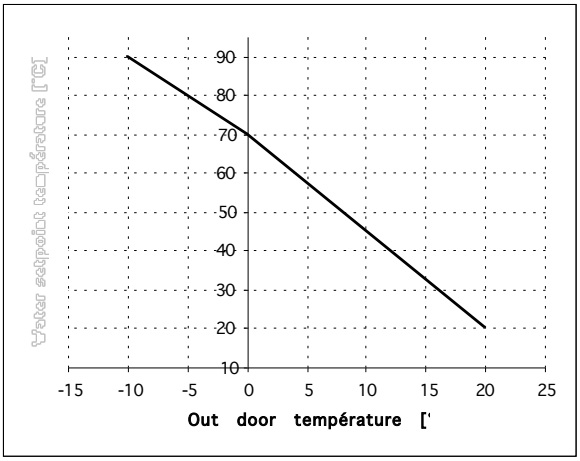

Figure 2: Boiler water set point

The supply water temperature set-point is controlled through a 3-way valve mixing return water and water from boiler. Fully closing the valve (0% opening) corresponds to fully recirculating the water without mixing it to water from boiler.

Possible defaults for the boiler are as follows:

- Boiler default (heat cannot be produced in the boiler).
- Outdoor temperature sensor default resulting in excessive or insufficient water temperature set point.
- Water temperature sensor default resulting in actually providing more heat than necessary.
- 3-way valve default resulting in no return water being circulated back and thus possibly excessive water supply temperature.
- Pump default : No flow in radiators thus resulting in no heating.

Ventilating systems

Mechanical ventilation is integrated and the air flow rate is supplied by the air pre-heated in the air handling unit. The flow rate is defined by occupancy schedules (full rate during occupancy. No ventilation when zone is empty at night and during week ends if appropriate schedules are selected).

The air handling unit preheats outdoor air at a constant setpoint (18°C) before supplying it to each zone. The maximum air flow rate is 750 m3/h (when all zones require ventilation).
The heating coil is dedicated to controlling the supply temperature at a fixed set point temperature during occupancy: 18°C. This is achieved by controlling the water flow rate in the heating coil using a 3-way valve.
The water temperature is the same as the one circulating in all radiators and is therefore a function of outdoor temperature.
Pressure difference is measured across the fan and the filter. Whenever their value is below specified limits indicating fan default or dirty filter, an alarm occurs.

CONTROL STRATEGIES

SIMUBEMS offers various control strategies for heating. Thus students can run simulations using five levels of complexity: manual control, on-off control, PID control, PID control with intermittence and PID control applied to a building energy management.

Manual control

Occupants are more willing to accept a wider comfort band when they have the possibility to control their local area, Osland (1994). However manual control increases the energy consumption and change the level of complaints of occupants, Bordass et al (1994). The aim of this part of SIMUBEMS is to lead ENTPE students to be aware of the importance of automatic control use in building. Indeed, a virtual instrument (figure 3) allows the user of SIMUBEMS to change the heating power according to the thermal comfort state displayed on the screen.

On-Off Control

This module introduces the most basic but also the most commonly used control technique. Incorporating an ON-OFF control in SIMUBEMS aims to familiarize ENTPE students with stability, comfort and energy On-Off control inherent problems. Therefore, students have to fit the dead band (or static differential) to the controlled system dynamics in order to avoid too important variations of the controlled variable around the set-point (figure 4). The selection of the dead band will actually influence:

❶ Actuators stability: The smaller the dead band, the most unstable the control variable will be
❷ Occupants comfort (variation of the temperature around the set-point can be

perceived in a negative way if their amplitude and frequency are both too large).

❸ Energy consumption: Though not obvious, the selection of the dead band has an important impact on energy consumption.

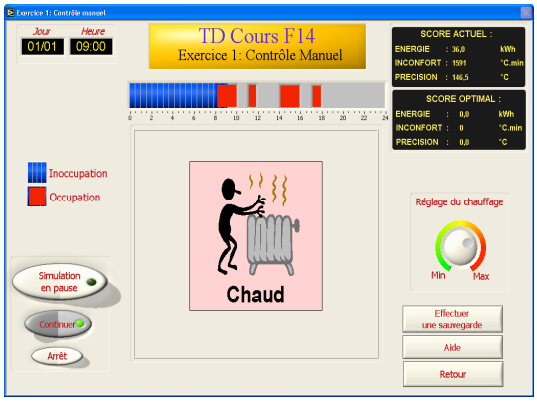

Figure 3 : Manual control

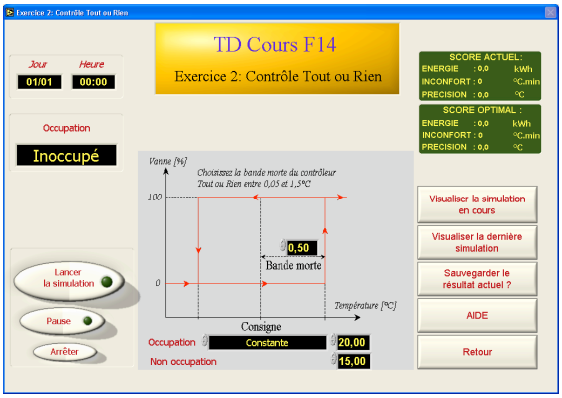

Figure 4: On-Off control

PID Control

In buildings, PI (or PID) controllers are usually used in HVAC systems for heating and cooling valve control in Air Handling units or 3-way valve control in a hot water network for radiators or fan coils supply. Initially, PID control part of SIMUBEMS allows students to modulate the controller's output and thus to test finer control of heating.

Since PID controllers are sensitive to system dynamics and could result in important instabilities if not accurately tuned, SIMUBEMS gives also the possibility to set PID controller parameters using Zeigler-Nichols method , Flaus (1994) (figure 5).

Building Energy Management System

The final level of SIMUBEMS aims to use the PID controller tuned previously in a building energy management system (figure 6). In order to take the thermal masse of the building into account, a pre-heat time (at full heat power) is included before occupants arrival in the morning. ENTPE students have thus to adjust the pre-heat time in order to insure acceptable thermal comfort at the lower energy cost possible. In this part seventeen alarms can randomly occur. Alarms concern either actuators or sensors breakdowns.

Example of actuator breakdown: *Pump default (no more hot water circulating in radiators).*

Example of sensor breakdown: *Breakdown 17 : Outdoor air temperature sensor default (indicating 0°C).*

Students have to quickly acknowledge each alarm because the longer they wait the more important the consequences will be.

ASSESSMENT

Once a simulation has been performed, the user is given the possibility to evaluate the performance of his choices. Indeed, SIMUBEMS offer provides information on thermal comfort and energy consumption for any simulation previously performed. Explanations on different alarms and their consequences are also summarized.

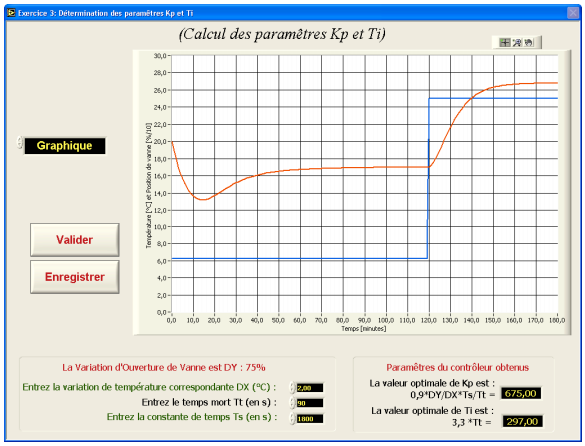

Figure 5: PID controller tunning

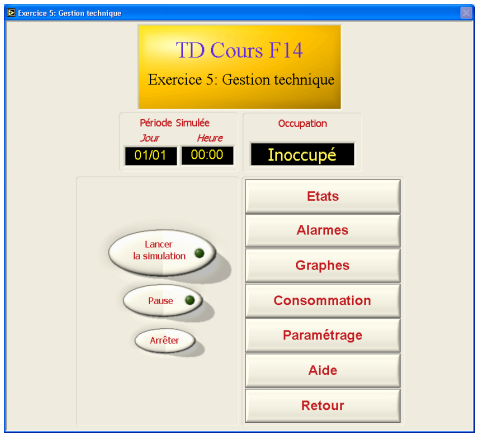

Figure 6: BEMS window

CONCLUSION

The educational tool on control strategies, MEDIABEMS, has been tested by ENTPE students during more than three years. This tool has been largely appreciated and has contributed to a good understanding of Building Energy Management System process. Other numerical and experimental tools intended to teach natural ventilation techniques and advanced control strategies based on fuzzy logic control have also been combined with SIMUBEMS in order to initiate students to a global management of the building.
Currently, studies are carried out at the laboratory of building sciences (ENTPE/DGCB/LASH) in order to extend the population focused by SIMUBEMS to architects, building owners and decision makers.

REFERENCES

Levermore G V. (2000). Building Energy Management Systems, Applications to Low-Energy HVAC and Natural Ventilation Control, E&FN SPON.

Michel P, Cantin R, Guarracino G, Santamouris M, Sutherland G, Nolay P and Kaiser P. (1998). Mediabems multimedia educational package on building management systems, Proceeing of EPIC conference, Lyon.

Osland N. (1994). A review of thermal comfort and its relevance to future design models and guidance. Proceedings of BEPAC Conference. New york.

Bordass W T, Entwisle M J, Willis S T P. (1994). Naturally ventilated and mixed-mode office building: Oportunities and Pitfalls. Proceeding of CIBSE National Conference – Vol 2. Bringhton.

Flaus J M. (1994). La régulation industrielle : Régulateurs PID, Prédictifs et flous, Hermes, Paris.