

Controller design for climate control in buildings using CLIM 2000

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Abstract

The CLIM 2000 software environment [1] was developed by the Electricity Applications in Buildings Branch of the French utility company, Electricité de France. This software which has been in operation since June 1989, allows the behavior of a whole building to be simulated. During the last phase of development, special attention and hence research resources were devoted to developing an open-ended software package where new component models could be added in a user friendly way. The new components that underwent development were: 1) directed at today's demands for analysis of the occupant's comfort; 2) the comparison of different heating or ventilation systems; and 3) the pertinence of a complex control system's to meet the demands.

The scope of this paper addresses the latter of the third area. In this paper, a new open ended complementary CLIM 2000 computer controller simulation interface, and controller modules developed during a one year period are presented. These new modules or tools denoted as *CLIM 2000 - MATLAB connection* provide the users with efficient analysis of system properties: performance and robustness. In addition, these tools allow the user to evaluate complexity (pertinence) of the design verses its system performance by comparing alternative designs in a user friendly environment. More specifically, an efficient controller prototyping environment (controller interface library) is presented using different type of controllers: PI with bang-bang, fuzzy and predictive control strategies.

Keywords : modelling, simulation, controller interface.

Introduction

Although a building is intuitively a simple structure composing of four walls, a floor, a ceiling, a door, etc.. The model is anything but simple. Typically a building's model is of high order, MIMO (in nature due to the many external influences) and necessitates a structured computer interface to construct.

In recent years, the department of ADEB, launched a major project to develop an in-house multifaceted building simulator called CLIM 2000 [1]. Today, the simulator is used to performed economy studies on energy usage in housing. Along with the elementary component models representing walls, ceilings, floor, doors, etc., a data base of external weather data is integrated into the software. Hence, the user now has a powerful tool in which to test efficiently new concepts and develop more accurate and detailed models.

Along the direction of control, the well-known comfort control problem has been difficult to resolved. And in many cases, the design has been made via a case by case effort.

On the control side, the problem has been the lack of a representative model of the process and its interaction with the environment. Hence, given a representative model, and the wealth of today's controller design tools combined, practicable cost effective solutions are now within reach.

In order to close the gap between the availability of the model and the control design tools, a new project was launched in 1995 to connect CLIM 2000 to MATLAB (Matrix Laboratory) in order to use existing controller design tools, [2].

The principle objective of the study in [2] was to determine the feasibility of the CLIM 2000-MATLAB connection in developing comfort controllers for buildings. The constraint was clear: the new connection must provide a computer framework where the control design is focused on comfort control and less on programming of the basic controller design tools.

1. CLIM 2000 - MATLAB Architecture

Figure 1, illustrates in block diagram form the essential elements of the existing CLIM 2000-MATLAB connection.

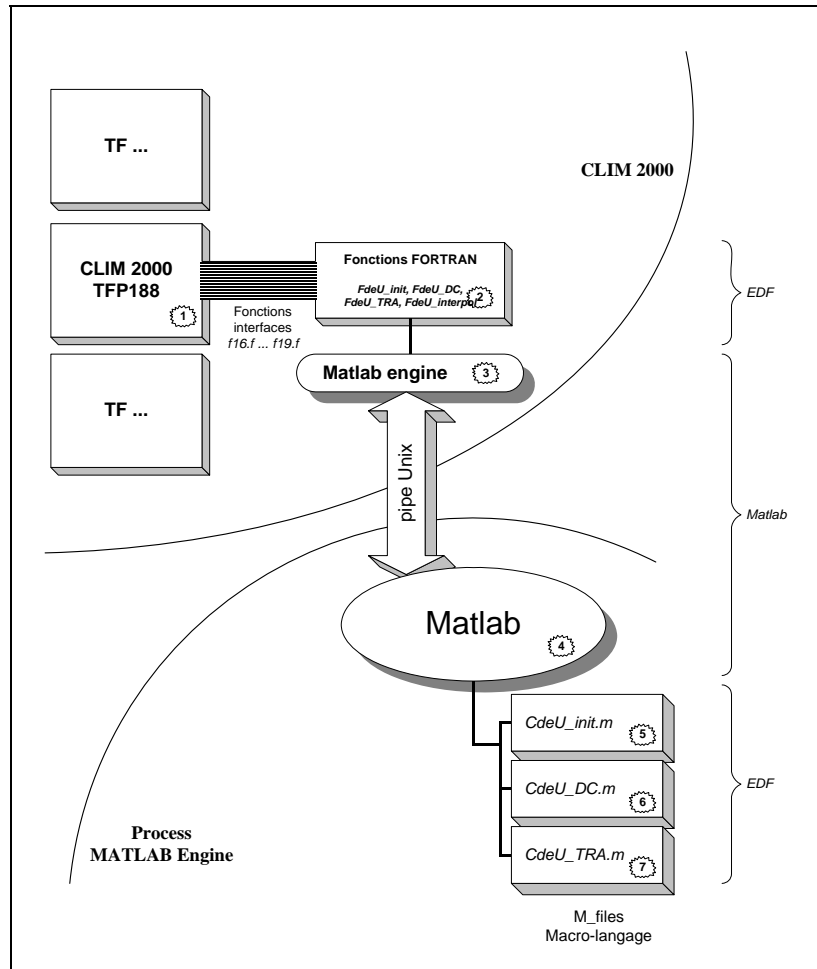


Figure 1: - Architecture CLIM 2000 - MATLAB

In brief, the user selects and implements the model called TFP188 in his study in a standard way (the TFP188 is described in detail below), [1]. As is shown on the figure, the information (parameters) from this TFP as well as the computed control signal are transmitted using CLIM

2000, built in FORTRAN interface (see [3]) which calls generic FORTRAN routines (FdeU_INIT, etc...) These subroutines call system routines which launch the MATLAB application [7]. MATLAB execute sequences of commands (controllers) that are stored in files, called m-files. This process is illustrated in the diagram by a two way transfer from the CLIM 2000 process to the MATLAB process.

2. Controller usage in CLIM 2000

The use of the Controller connection in the CLIM 2000 environment is essentially transparent to the user. This is achieved by the use of a new Formal Type (denoted TFP188) coded and used as any other CLIM 2000 Formal Type.

At the user level via CLIM 2000's graphical interface, the input-output description of the TFP188 icon is illustrated in Fig. 2.

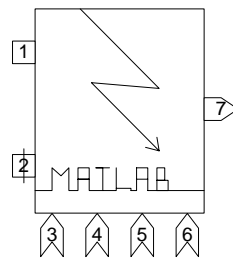


Figure 2: ICON representation of the TFP188 model.

The TFP188 is comprised of 6 input connections or pallets and 1 output connection. In particular, pallets number 1 and 2 are respective the measured and setpoint variables. Pallet number 7 is the output (typically a heating command). In addition, 4 extra pallets are available to the user. There exact definition depends on the specific control algorithm used.

As with other Formal Types, the specific use of the TFP188 requires the definition of internal parameters. In the present case, these internal parameters are:

Symbol	description	Range
Nalgo	Algorithm number	≥ 0
Tech	Sampling period	≥ 0
Umin	Minimum value of the control	$] -\text{inf}, +\text{inf}[$
Umax	Maximum value of the control	$] -\text{inf}, +\text{inf}[$
P1 to P10	Addition parameters	$] -\text{inf}, +\text{inf}[$

Table 1 : TFP188 parameters.

In summary, the 4 parameters (Nalgo, Tech, Umin and Umax) are fundamental to the operation of the TFP188. They define:

- Nalgo - selects a specific control algorithm,
- Tech - specifies the sampling period,

Umin - sets lower limit of the output,
Umax - sets upper limit of the output

The remaining 10 parameters provide additional flexibility to the user. In particular, these parameters provide the user with additional algorithm options.

As with other Formal Types, all input-output signals and internal parameters can be saved automatically. They are specified in the standard way via CLIM 2000's interface.

3. Applications

In this section, two examples illustrating the use of the CLIM 2000 - MATLAB connection are presented. In addition, these examples demonstrate the key aspect of the new connection in solving current regulator problems in buildings. At present, the discrete controller library contains:

- PI with bang-bang
- Fuzzy control
- Predictive control

In example 1 a single regulator (PI with bang-bang) and a fuzzy controller are investigated for use in room temperature control. The general conclusion was that in order to achieve the objective an anticipative heater launch scheme is needed. In order to achieve this, a predictive control law was sought. Hence, the second example illustrates the use of MATLAB's Predictive control toolbox.

3.1 Example 1 (PI and Fuzzy control)

Figure 3 illustrates a single family residential house (Mi2). The figure represents the building components using circuit analogies. That is, each bloc corresponds to networks of resistors and capacitors and the connections points as nodes. As is seen, the room temperature is connected to terminal (node) 1; the setpoint is provided by the TF45 (signal generator) connected to terminal 2. The output terminal is connect to the input to a TF46 (electric heater). The remaining 4 input terminals are not used and are set equal to zero via a TF13 (constant output).

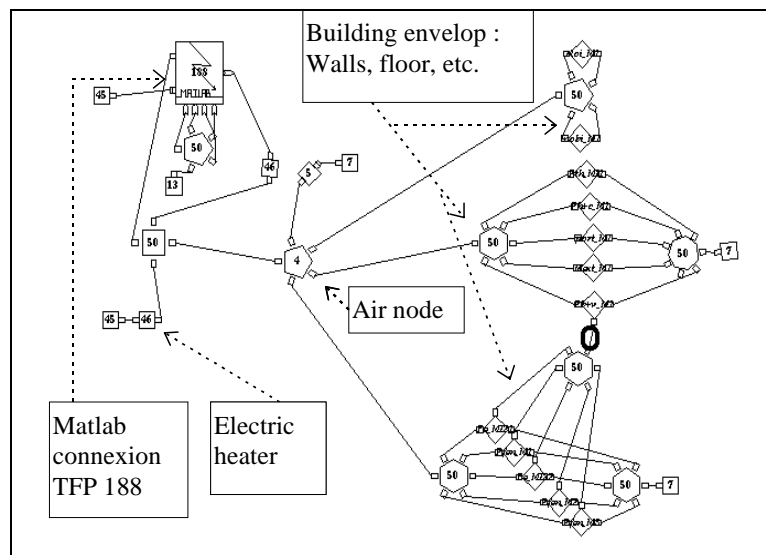


Figure 3: - CLIM 2000 graph of Mi2 with P and Fuzzy control.

In this example, the control objective is to obtain and hold a square-wave like setpoint temperature in the Mi2 house. In particular, the setpoint is cyclic with 14 °C from 12:00 PM until 8:00 AM where the setpoint temperature is 19 °C. Again at 6:00 PM, the setpoint is set at 14 °C until the following day where the cycle repeats, Fig. 4. Dashdot curves represent fuzzy controller response. Solid lines show the PI regulator.

The fuzzy regulator is built by Fuzzy Tech. Fuzzy Tech is a fuzzy environment developed by Inform (Germany) which generate m-files for MATLAB.

As is clearly illustrated in Fig. 4, the regulation objectives are obtained with PI and Fuzzy control. However, it took approximately 2 hr. to arrive at the setpoint.

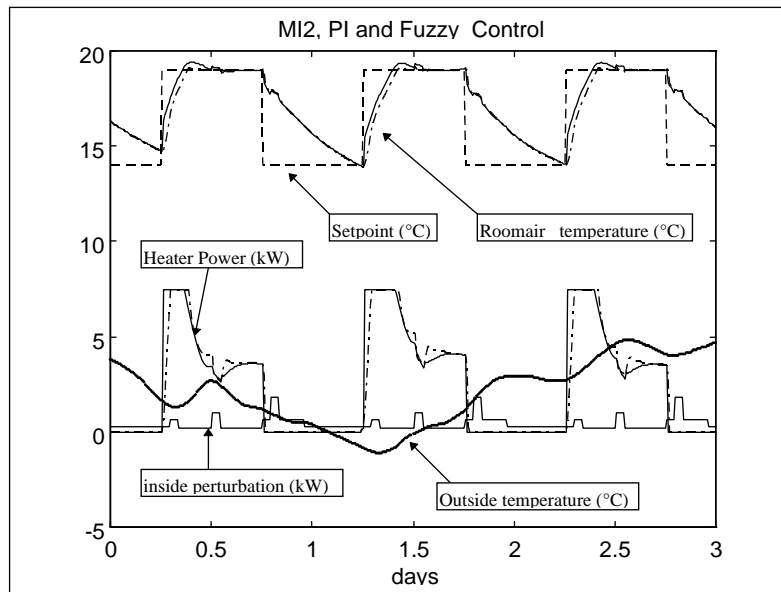


Figure 4 : Temperature and convector power evolution's

That is, the occupants would probably consider the room to be too cold or uncomfortable. The comfort band is known to lie between one half degree of 19 °C. It is clear from the heating command which correctly starts at full power that it is impossible to do better than this without additional power. That is, the temperature trajectory's rise time illustrated in the figure is increasing with a time constant of approximately 6 hour which is defined by Mi2's dynamics. Clearly, the solution is to either augment the heater power or launch the heater earlier.

The first alternative could be prohibiting as the cost to the consumer would increase. However, the additional power is clearly only needed to achieve the setpoint (small percent of total heating operation) as compared to the original heater which provides good regulation (most of the operation time). Hence, it is natural to conclude that launching the heater earlier would reduce consumer costs and provide comfort through out the heating day.

In the context of this section, the PI and Fuzzy controllers are implemented in MATLAB via a m-file. With respect to the CLIM 2000 - MATLAB connection, there was no need to recompile the controllers or re link. All changes were directly included into a text file and a new simulation run. In this way, the developer can readily introduce his/her ideas in a efficient manner.

3.2 Example 2 (Predictive control)

As was the case for the PI and fuzzy controller examples in the CLIM 2000 - MATLAB connection, the same TFP188 is used here to regulate the room temperature. The difference here is that the Model Predictive Control Toolbox (MPC) [6] is used. The MPC Toolbox is a collection of functions developed for the design of model predictive control systems. This package is intended for the practising engineer. The predictive law is developed with routines which use a step response model description.

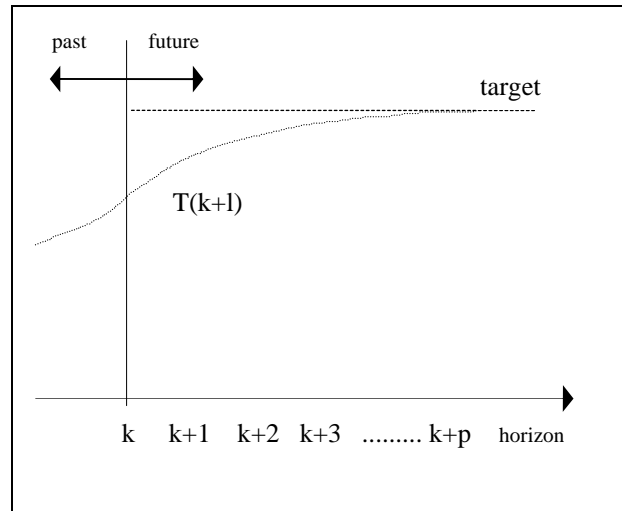


Figure 5 : Principle of predictive control

For any assumed set of present and future inputs $u(k), u(k+1), \dots, u(k+m)$ the future behaviour of the temperature $T(k+1), T(k+2), \dots, T(k+p)$ can be predicted over a horizon p . The m present and future inputs are computed to minimise a quadratic objective of the form :

$$crit = \sum_{l=1}^p (W_t(k+l) \times (T(k+l) - r(k+l))^2) + \sum_{l=1}^m (W_u(k+l) \times u(k+l)^2)$$

Where W_t and W_u are weighting vector to penalise particular components of T or u at certain future time interval. $r(k+l)$ is the vector of future reference values (setpoints).

At next sampling interval, new values of the output are obtained, the control horizon is shifted forward by one step, and the same computations are repeated. The resulting control law is referred to as « moving horizon ».

Similarly to the first example, the room temperature is connected to terminal 1; the setpoint is provided by the TF187, [2] connected to terminal 2. Specifically, the TFP187 provides the future value as well as the current setpoint values for use by the MPC toolbox. These values are passed to MATLAB via the terminals 2, 3 and 4 (see Fig. 2 et 6). The TF50 assures that the input to terminal 2 and 3 are the same. The output terminal is connect to the input to a TF46 (electric heater). The remaining 2 input terminals (5 and 6 are not used and are set equal to zero via a TF13 (constant output).

In this example, the control objective is also to obtain and hold a square-wave like setpoint temperature in the Mi2 house, Fig. 6. In particular, the setpoint is cyclic with 14 °C from 12:00 PM until 8:00 AM where the setpoint temperature is 19 °C. Again at 6:00 PM, the setpoint is set at 14 °C until the following day where the cycle repeats.

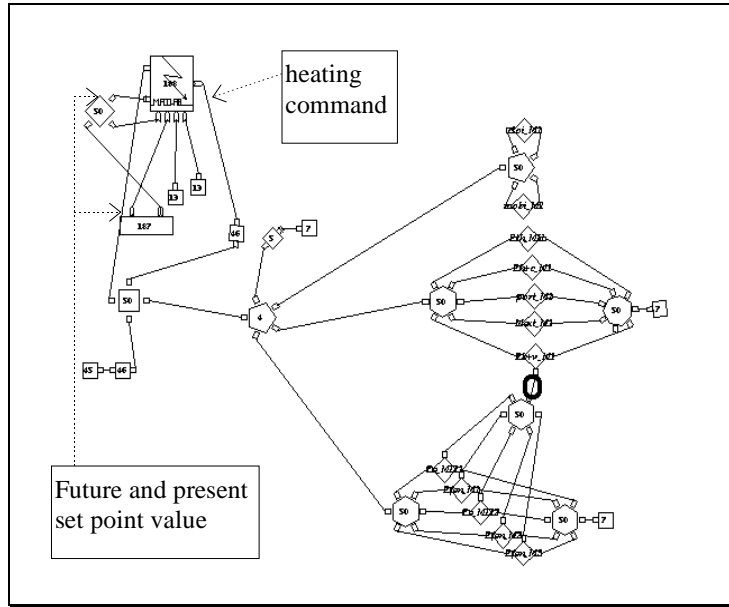


Figure 6: - CLIM 2000 graph of the Mi2 with MPC control.

The results of the simulation are summarised below in Fig. 7. The main three curves are: the desired room temperature setpoint; the actual room temperature; and the heating command. As is clearly illustrated in the figure the control objectives are obtained with very good regulation. The conclusion is that the predictive regulation scheme is a significant improvement of that of the classic PI solution.

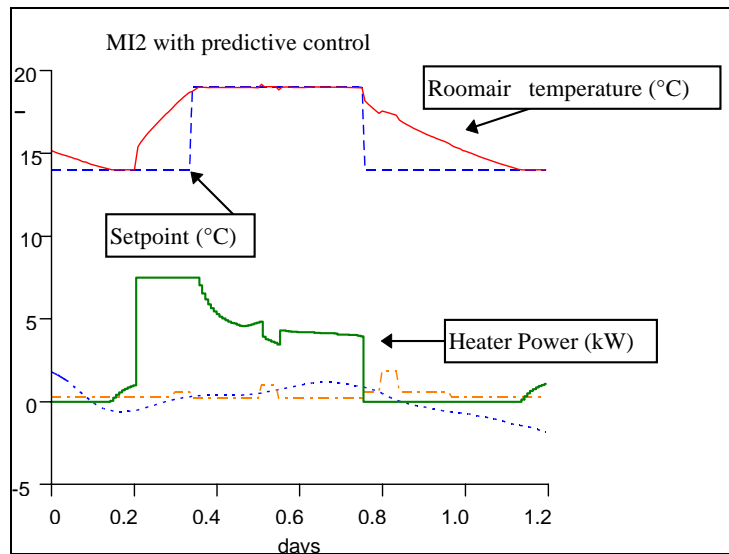


Figure 7: - Temperature and convector power evolution's.

With respect to the complexity of the present algorithm, (see [6]) it is important to point out that the user need only clear shown in Appendix B under NAlgo = 4, that the controller algorithms is not overly complex.

With respect to the CLIM 2000 - MATLAB connection, it is seen that the use of highly advanced controller algorithms is almost transparent to the user. That is, the user can efficiently investigate the use of well tested MATLAB toolboxes in comfort control problems. In this case, the user provides the information needed by the Toolbox routine via the TFP188 CLIM Block (as

in Fig. 6). The TFP188 via the connection transfers this information to MATLAB where the control is computed.

4. Conclusion and future work

In conclusion, this paper has illustrated the key aspects of the CLIM 2000 - MATLAB connection controller simulation interface which provide the developer and simulation team with a powerful decision and design tool. At the technical level, an efficient sensibility (simulation based parameter optimisation) are easily performed. In particular, the controller parameters are introduced via the CLIM 2000 interface and a new simulation is run which is automatically documented and archived using 'catapost'. If the developer chooses to make a change to the controller, he can do so without affecting the integrity of the simulation. That is, post-treatment of the simulation data is still possible via CLIM 2000's standard process.

On a more general level, the controller simulation interface can be used with other simulation programs. This is made possible by the nature of the controller interface. Any change in a controller's m-file can be considered as a change of how the TFP188 calculates the output given its inputs and internal parameters which can be accomplished without re-compiling connection.

Further improvements on the controller interface library are currently being pursued. In particular, a more general self contained FORTRAN/C interface library is under development that will provide the user with access to a larger environment of computing resources. These improvements are expected to retain the simplicity of the current MATLAB connection via a m-file approach when connecting to MATLAB and a similar approach using FORTRAN/C coded algorithms.

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