ADAPTATIVE PREDICTIVE CONTROL IN INTELLIGENT BUILDINGS

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SUMMARY

This paper discusses the various problems which an integrated facilities management system in an intelligent building must deal with in order to optimize the various building services as well as the consumption of energy. Air conditioning control and energy management are covered as fundamental aspects. The PID traditional control system commonly used are described and their methodology and performance is compared with that the new Adaptative Predictive Control Systems (APCS). The way in which these systems solve the previously considered problems, as well as the advantages of APCS with respect to traditional PID are illustrated and highlighted.

1 INTRODUCTION

The modern conception of a bulding construction project includes the incorporation of equipment and processes of a high level of technological sophistication, intended to make the facility more habitable and more economical in operation.[1]

The complexity of these processes and equipment, and the superior performance required of them . necessitate the application of a system capable of controlling all of the various equipment items, coordinating their operation and integrating its supervision in order to optimize both the services and the operation of the building. A building equipped with such a control system can properly be termed an "intelligent building".

This document begins by setting forth, in layman's terms, the basic concepts of control systems. their objectives and the services to wich they are applied in a building. These considerations are followed by a review of the factors involved in air conditioning and comfort and the optimization of energy use.

The classic control solutions available on today's market are discussed. Finally the Adaptative Predictive Control System (SCAP) are show to constitute an optimal solution of the requeriments of an intelligent building.

2 CONTROL SYSTEMS IN INTELLIGENT BUILDINGS

Controlling a process consists of performing the appropiate, called control actions, to maintain certain variables at pre-set values.

For example, the temperature in a room could be the variable to control. If this variable were to rise above a certain level the pre-set value a window could be opened to lower it: opening the window would be the control action. An electronic control system acting automatically on an air conditioner to regulate the flow of cold air coming out of the ventilation system would solve the same problem in an automatic manner which could be schematically described as in Figure 1.

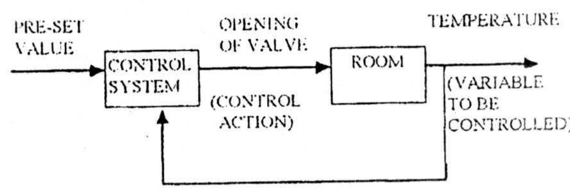


Figure 1

In order to be able to achieve an automatic control of the different variables in an environment or process. appropiate sensors are needed to give reliable measurements. The control system acts, with a pre-established periodicity, on each one of the necessary elements, to include valves, switches, motors, etc., to lead the evolution of the variables to the pre-set level.

The objectives to be attained through the control of facilities in an intelligent building are:

*To maintain the variables which determine comfort at their most suitable values.

*To minimize energy consumption through optium control of all equipment involved.

*To identify and locate any alarm situation at the moment it arises. and to take the appropiate corrective measures.

The automatic and integrated management of the facilities in a building consists of the performance, without human intervention, of all the control tasks tending to the achievement of these objectives.

An automated management system must also make it possible to:

-Concentrate all the necessary information for the proper operation of the equipment items, as well as for their preventive maintenance.

-Rapidly and easily modify or add new equipment to the facilities.

3 SERVICES IN A BULDING

Various independent services, each with a specific mission or missions, coexist within a building. While they are all necessary for the proper operation of the building, their differing natures require differentiated treatment.

These services are:

-Air conditioning
-Hot water
-Lighting
-Groups of elevators
-Guarding and access controls
-Detection and extinguishhing fires

These services can be integrated into a single system, or be grouped by areas according to needs of security, distribution of responsibilities and different types of personnel in charge of each area.

4 AIR CONDITIONING AND COMFORT

The significance of air conditioning as a fundamental factor in achieving comfort must be emphasized, as well as its importance in optimizing energy use.

There is no doubt that comfort is the most important factor in the conception of an intelligent building,[2] for it cannot be forgotten that buildings are designed to be used by people, and that people will be more productive in their different activities when conditions of comfort are the most suitable. Effective air conditionig is the principal means of achieving optimun comfort.

4.1 Ambient conditions which determine comfort

To subsist, a human being needs to consume some 12,000 liters of air per day. This fact confers special importance on the air quality that must be assured in a building. To achieve adequate air quality, the agents which modify it must be known so that they can be acted upon.
Human respiratory activity progressively reduces the oxygen content of the air, and can make in unbreathable in closed spaces. It is therefore necessary to insure an adequate renewal of the air supply to keep it breathable.
Moreover, human metabolic activity produces body heat, which enables individuals to maintain the body temperature of 37°C required to carry out organic functions. The body generally releases heat into the ambient air through the skin, through respiratory exhalation and perspiration.

These factors make it necessary to insure that the temperature, humidity and speed of the ambient air permit the body to release the heat it must yield to maintain its correct temperature without effort. This is because the sensation of physical well-being vanishes when the equilibrium between the heat released and the heat produced by the body is broken.

The applicable ITIC standars set the limits of these variables at a minimun of 20 degrees Celsius and 45% humidity in winter, and at a maximun of 25°C and 55% in summer. UNE standars define these values as being within the area of well-being.

4.2 Agents which alter ambient conditions

Comfort conditions can be altered by different causes, to include the following:

-Difference between outside and inside temperatures
-Solar radiation striking the building
-Operation of machinery
-Lighting
-Human activity

The influence of these factors on the internal atmosphere of a building is highly variable across time and is not clearly nor precisely predictable.

4.3 Control of ambient conditions

Various actions can be taken to control ambient conditions, specifically:

-Heating or cooling the inside air
-Ventilating with air conditioning
-Variying the amount of solar radiation received, by means of reflecting or opaque surfaces
-Filtering the air
-Variying the intensity of artificial lighting

The optimun control of the air conditioning of a building requires the capacity to anticipate changes in ambient conditions and to adapt to the different external and internal conditions which can arise at

any time. Such a control will guarantee a minimum consuption of energy.
There are a number of options available in the market for the automatic control of air conditioning equiopment. However, the majority of them do not assure an optimun control. In the discussion of APCS system in this article, the optimun solution is presented.

By turning off the air conditioning equipment, or by maintaining a temperature that is below the comfort level, during the time the building is unoccupied, a significant energy savings can be achieved.

5 TRADITIONAL CONTROL SYSTEMS

Traditional control systems are based on PID negative feedback methodology.

In PID controllers the variable to be controlled is subtracted from the pre-set value or setpoint and, based on this difference or error, the system calculates the control action as the sum of proportional, an integral and a derived control action. (fig. 2)

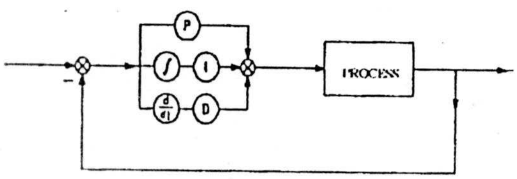


Figure 2

The simplicity of PID systems is a great benefit, and is the characteristic which has led to their wide use in the market, first in the area of pneumatic technology, then in analog electronics and finally in digital electronics by means of microprocessors and computers.

Their great limitation. However, derives from the problem of stability, wich is analyzed in in the section below.

5.1 The problem of instability

If users of equipment wish to control a variable of its operation, it is because the natural tendency of that variable is to drift away from the desired value and because, in particular, it tends to oscillate. If this situation never arose, the problem of control would not exist.

Generally, the setpoint is a constant. Therefore, when oscillations are subtracted from the variable, they are reproduced in inverted form at the error signal level.

So that the control will make a quick response which significantly corrects the error, the PID controller will tend to act as an amplifier. As a result, an oscillation of the error signal will which we wish to control. This moves us toward, or reaches, the well known phenomenon of resonance (fig. 3).

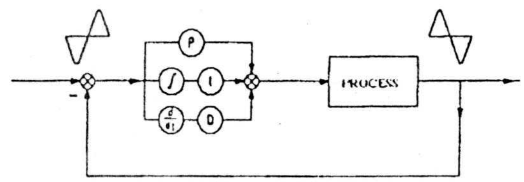


Figure 3

To avoid oscillations brought about by the stability problem, the controller can slow down its response by means of the manual adjustment of its PID parameters. However, while oscillations are avoided in this way, major errors are generated over long periods of time.

5.2 Example of PID control

In the following paragraphs we will use an example to analyze the behavior of PID control applied to an air conditioning system (fig.4).

Let us take the case of a room at 7 in the morning, whose temperature is 12°C, a value we wish to increase to 20°C before 8 a.m. This means that we want to achieve a fast transition, which will imply some major oscillations, probably between 24°C and 16°C.

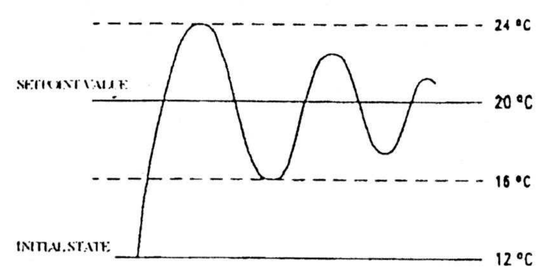


Figure 4

In order to avoid letting the temperature fall below 20°C, the operator could change the setpoint to 24°C. This action would shift the oscillations upward, that is, to an area between 28°C and 20°C.

These cyclical overheating episodes obviously result in an unnecessary use of energy (represented in the graph by the shaded area), and in an excessive drying of the ambient air (fig. 5).

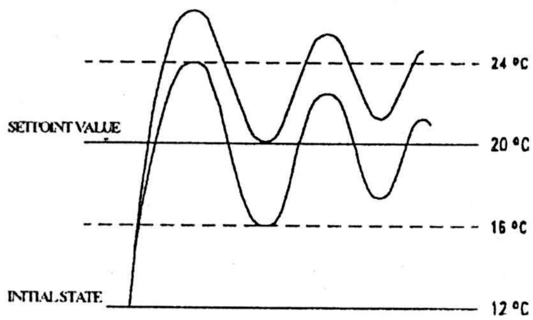


Figure 5

6 ADAPTATIVE PREDICTIVE CONTROL METHODOLOGY (APCS)

6.1 Basic concepts

Many of the great steps forward in the technological era we live are have been made possible by the advent of digital computers. Computers enable us to perform more complex operations than those of a PID controller; specifically, they allow us to store parameters and variables, and consequently, to store a model. We define a model as a set of equations which relates the inputs of a process with its outputs.

All processes involve an output which the operator wishes to control an d the control signal which is manipulated.

Predictive control uses the model of the process to be controlled to predict the evolution of the process output variable and to calculate the control signal which will make that predicted evolution equal to the desired evolution. That is, predictive control is what makes predicted equal to desired.

When predictive control is used, and the model of the process is capable of predicting satisfactorily, then all the stability problems which are characteristic of the PID negative feedback methodology disappear, since predictive control makes it possible to drive the process to the desired point in the desired way.

Obviously, if we have the capacity to predict accurately, we can calculate and apply the control signal so that what occurs is truly what we wnat to occur.

In real situations, we normally do not have a perfect model which will, from the outset, make an exact prediction of the process outputs. Moreover, the dynamics of the process can vary over time. For these reasons, an adaptation mechanism is required. This mechanism will correct the model based on its own prediction errors, which, under the influence of the adaptation mechanism, will tend toward zero as quickly as possible. In this way we arrive at the formulation of the Adaptative Predicitive Control System (APCS) as the ideal solution for process control.

6.2 Block diagram

The block diagram representing adaptative predictive control [3] is show in Figure 6. This figure shows how the predictive model predicts the evolution of the output and calculates the control signal which will make the predicted output. In turn, the desired output is generated by the driver block calculates the desired path to be followed by the process in order for it to reach the sectpoint value.

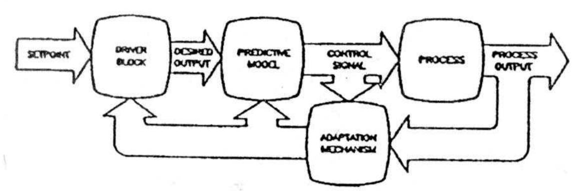


Figure 6

The adaptation or feedback mechanism operates on two levels.

-On the first level, it adjust the parameters built into the model so that the prediction error will tend to zero as rapidly as possible.

-On the second level, it informs the driver block of the current state of the process, and of the deviations of the process from the desired path. This information is used by the driver block to redefine this desired path. This second level of feedback complements the first, and makes sure that the control system responds in a manner which is coherent with the state of the process.

6.3 Example of adaptative predictive control

We will again take as an example the case of the air conditioning of an intelligent building, which is now under APCS control.

The initial temperature of the room to be heated is 12 °C at 7:00 a.m., and the desired output is that the room reach a temperature of 20 °C at 7:30 a.m. (fig. 7).

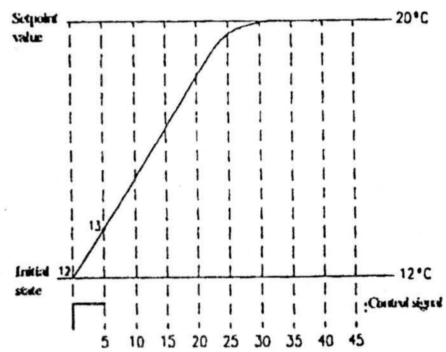


Figure 7

The driver block receives the set point of 20°C and present value of 12°C. Starting from that information, it generates the desired path which the temperature should follow in order to reach 20°C.

Assuming a control period of 5 minutes, and following the established process path, the temperature at the next instant (i.e., at the end of the first control period) should be 13°C.

This is the desired output for the next instant, the value which the driver block transmits to the predictive model, wich then calculates the control signal needed to make the predicted output equal to the desired one. This control signal could be, for example, a 50% opening of a valve.

The system applies the control signal and waits, during the five-minute control period, to receive the next temperature measurement.

At the following instant we can see that there was a prediction error: the temperature reached is not 13°C, but 12,5°C. In this situation, the adaptation mechanism reacts with its two levels of feedback.

The first level adjust the parameters in the model so that the prediction error will tend toward zero, and the second indicates to the driver block that the new temperature value is 12,5°C and not 13°C (fig. 8).

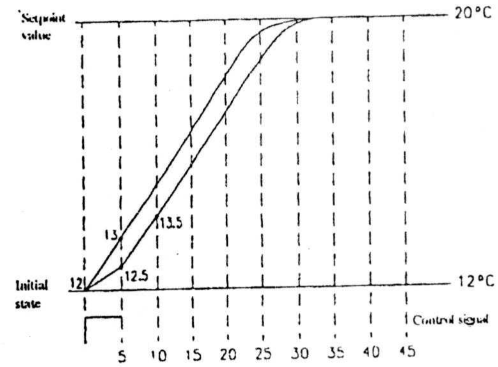


Figure 8

The driver block, taking the new starting point of 12.5°C into consideration, then generates a new path.

According to this new path, the temperature of the room should rise from 12.5°C to 13.5°C.

This latter value is the one which the driver block communicates to the predictive model so that the model will calculate the new control signal.

Let us suppose that the predictive model now generates a new control signal which is equivalent to opening the valve 70%. The system again awaits the response.

We observe that, after another five minutes, the temperature is not 13.5°C, but 13.8°C (fig. 9). In this case the prediction error made falls short of the mark rather than exceeding it.

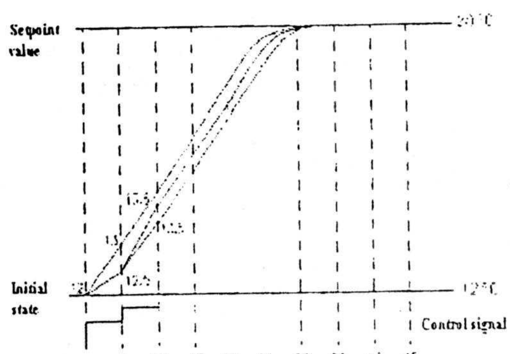
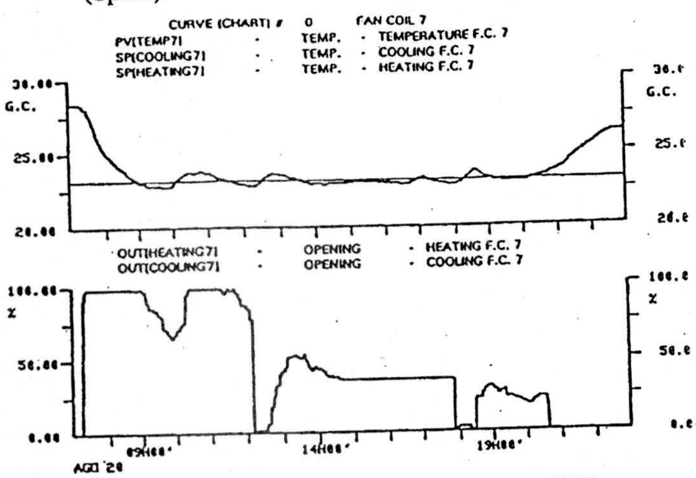


Figure 9

The system will now react in the same manner that we have seen before.

Thanks to the persistence of the system. the prediction errors tend rapidly to zero, and the different desired paths generated by the driver block tend toward a single path which is the one the process variable ends up following until it attains the setpoint of 20°C.

These theoretical results are well supported by experience. As an example of this, we can see, in Figure 10, the results of the application of an APCS system in the air conditioning of the Serantes building, located in the Azca complex in Madrid (Spain)



EXAMPLE OF AIR CONDITIONING IN THE SERANTES BUILDING

Figure 10

In this example we can observe how APCS acts during an entire day to maintain the temperature (upper graph), with a margin of variation of +/- 0.5°C, at the pre-set value. To this end, the valve which releases the cooling water which circulates through the fan-coil (lower graph) must constantly vary its position.Figure 11 shows a detail covering two hours of the same day.

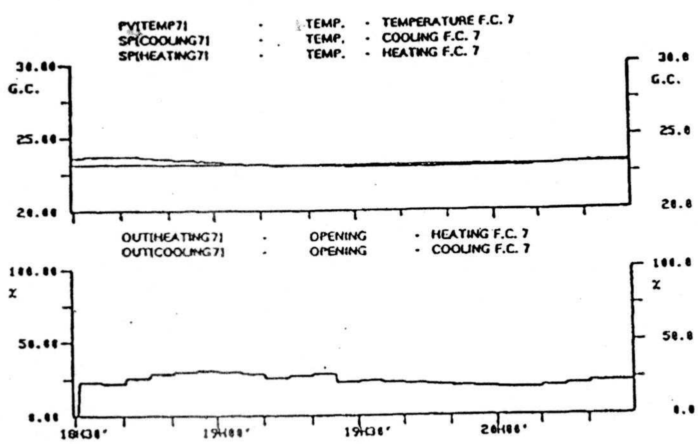


Figure 11

6.4 Comparison with traditional systems

When the APCS methodology is compared with PID negative feedback, it can be affirmed that APCS is a scientific, methodological solution of the control problem. a solution which is capable of driving the variable which its controls from a starting point to a set point . a long a path which is both optimum and oscillation-free. PID is a well know solution, in which certain parameters must be adjusted manually, always in a punctual manner that is, at a specific point in the operation of the process. Unfortunately, any specific point will vary in the course of the process. In an air conditioning process, the prope adjustment of a PID controller will not be the same at 8:00 in the morning as at 2 in the afternoon. Further. if a certain efficacy is desired in the response of a PID controller in general, significant oscillations around the setpoint will be unavoidable.

7 OPTIMIZATION OF ENERGY

Energy savings area key factor in the cost of maintaining a building.

According to different estimates. in the industrialized countries nearly 45% of the energy consumed by a nation is consume in buildings. This statistic highlights the importance of energy savings achieved in buildings.

There are various aspects which. taken together, make it possible to attain an optimum consuption of energy, Which is defined as the minimum needed to create and maintain the desired ambient conditions, and to assure the correct operation of equipment.

Inside a building. energy consumption is divided primarily between air conditioning (43%) and lighting (50%).

7.1 Lighting control

Controlling interior lighting at various levels at all times. the use of the minimumenergy permits. required to maintain sufficient lighting.

We can cite the following as specific actions to be taken by a control system:

-Turning off the lighting at programmed times
-Turning on lighting when human presence is detected
-Varying the light intensity in response to changes in external light

7.2 Additional energy savings through use of the APCS System to control air conditioning

By using the APCS System to control air conditioning, the degree of comfort required in any facility is achieved because the APCS System stabilizes variables without deviations from the established setpoints. This stabilization produces the additional benefit of energy savings with respect to conventional control systems, since the variables which the latter attempt to control oscillate around the setpoints.

In the following paragraphs we will show how the estimated annual energy savings is calculated under APCS control, in comparison with another control system which would be unable to maintain the temperature continuously at the ssetpoint. These savings are more significant in those cases where the final actuators are of the on/off type, which present an insurmountable difficulty for non-APCS control systems in maintaining the programmed setpoint.

Let us suppose a building with the following design characteristics:

-Refrigerating capacity of the cooling equipment for an average temperature jump of 6 degrees centigrade: 580 Kfrigories/hour, for which 176kW/hour of electric power are required.
-Estimated daily hours of operation: 12.
-Estimated days of operation per year: 365.
-Price of energy: $0.15 per kWh

Under these conditions, the energy consumed to produce an average temperature jump of 1 degree centigrade in one hour is 176/6=29.33 kWh/°C. The energy required, therefore, over the entire year with the air conditioning equipment operating 12 hours per day would be:

$$29.33 \times 12 \times 365 = 128{,}465.4 \text{ kWh/°C per year.}$$

Bearing in mind the price of enrgy, on the average, each additional degree of unnecessary consumption entails an annual expense of $19,269 which can be saved under APCS control.

7.3 Other energy-saving measures

The limitation of power consumption peaks by turning off those elements which are not absolutely necessary also permits an energy saving derived from electric power pricing structures, due to the surcharges which are typically applied when the contractually agreed power consumption level is exceeded, even if only for brief periods. Only by constant monitoring is it possible to know exactly when power consumption peaks occur, and to avoid them. Moreover, this constant monbitoring provided by APCS systems ,makes it possible to calculate the battery of condensers needed for idle power compensation.

The optimization of elevator movements could also produce significant energy savings, as well as minimizing the waiting time to use elevators.

8 CONCLUSION

This article has discussed the various problems to which an advanced computeer-based facilities management system must respond, with special emphasis on the problem of control.

The APCS systems have been described and it has been shown how their application resolves all these problems in the optimun way.

The advantages of these systems can be summarized in the following points:

-Optimun control and stabilization of difficult processes, such as air conditioning, without the need of any adjustments other than the initial system configuration which is perfectly well defined.
-Aditional minimization of energy consumption.
-Minimization of project instrumentation cost, due to the fact that variable volume boxes are unnecessary, and because proportional valves in fan-coils can be replaced by on/off valves.
-Centralization of the information pertaining to the various services in the building.
-Ease of maintenance of the system as a whole.

The result is greater effetiveness, ñess intervention by the operator, greater security and guaranteed savings based on the use of today's most advanced control technology.

References:

[1] A.Viti. "General Considerations on intelligent buildings comfort and their relation with energy efficiency". Evaluación del Medio Ambiente Interior en las Edificaciones y Rehabilitación Medioambiental. Instituto Eduardo Torroja. CSIC. Madrid. June 1998.

[2] O.Rio. "Energy saving on the Conceptual design of intelligent buildings". Evaluación del Medio Ambiente Interior en las Edificaciones y Rehabilitación Medioambiental. Instituto Eduardo Torroja. CSIC. Madrid. June 1998.

[3] J.M.Martin Sánchez y J.Rodellar. "Adaptative Predictive Control: From the Concepts to Plant Optimization". Prentice Hall International. 1996.