SMART AUTOMATIC CONTROL OF ENERGY FLOWS IN BUILDINGS

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ABSTRACT

A general scheme of a system able to control the energy flows in a building is illustrated. A high quality system for home building applications, characterized by plenty of useful secondary services, is illustrated using a distributed smart system. The flexibility of the system shown allows different applications and useful functions to be developed.

Keywords: smart systems, energy management.

1. INTRODUCTION

Nowadays a lot of different system architectures can be used to manage and control the energy flows inside a building [1-8]. Their differences lie in their features and performance and obviously on the cost necessary to install them [9-12].

The scope of the controller system is obviously to acquire the environmental informations through appropriate *reading points* and act on the building installations through appropriate *action points*. In the following we call them *points* for brevity.

The controller systems can be divided into three main groups: central smart system, central smart system with bus and distributed smart system. All of them show positive and negative features, depending on the point of view of the analysis.

1.1 The Central Smart System

Central smart systems are characterized by a main controller system that is connected to the single point by means of a dedicated connection wire.

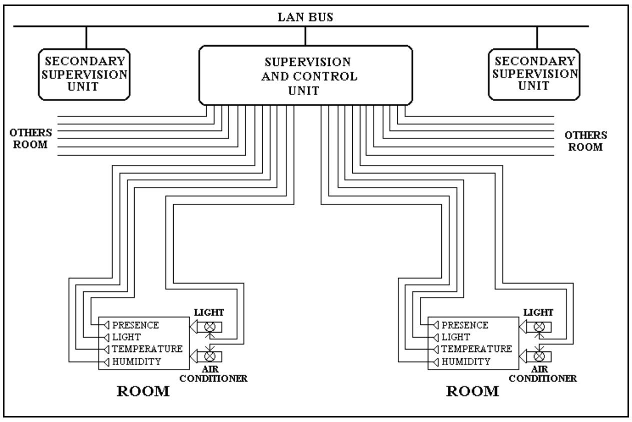

Figure 1.: Scheme of a central system.

The advantage of this kind of system is that great computation power and a large amount of memory is available to execute a large number of operations. Their disadvantage is represented by the need for transmitting each item of information from the peripheral point to the central system and vice versa. These operations will unavoidably slow down the operating speed of the whole system and expose the building to the danger of total loss of control. Further, since each operative decision is made by the central system, a failure of the central system implies a complete shut-down of the whole installation. Moreover, due to the need of connection of each point with the main system, two inconvenient problems appear. The first is that the data to be transmitted or received are subjected to corruption, due to the long distance to the final destination. This is not a problem if data are transmitted digitally because of the capability of error detection and correction, though at an increased cost of the system, but it could represent a great problem for analogue transmission. The second inconvenience is the high cost of installation of the system since each connection wire must be installed from the center to the peripheral point manually, and therefore the cost greatly increases with the distance and the complexity of the system. This last inconvenience make the cost of the centralized system dependent on the hourly cost of the work force, and therefore on the place where it is installed.

1.2 The Central Smart System with Bus

The central smart system with bus represents a mixture between the central smart system and the distributed system.

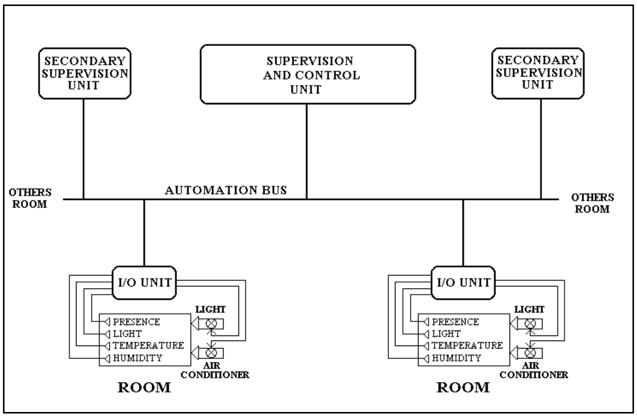

Figure 2.: Scheme of a central system with bus.

The bus is a physical means through which the information from the center to the peripherals and

vice versa are transmitted. The peripheral modules are only capable of executing input/output operations but they are
not able to execute smart programs or automatic operations, since each action is governed and authorized by the central unit.

This system allows a great reduction of the number of wires and a consequent reduction of the cost of installation, but it is exposed to the risk of bus failures that would stop the whole system.

1.3 Distributed Smart System

The distributed smart system is characterized by a variable number of low cost microcontrollers, interconnected according to different configurations, where each unit controls a certain number of points. The advantage of this kind of scheme is that the smartness of the system is distributed all over the system and the malfunctioning of a controller does not imply a loss of control of the installation but only the malfunctioning of the controlled zone. This inconvenience, because of the low cost of the controller, can be avoided using a reserve device, that is activated when the main device fails to perform its task. Further, the transmitted data are less subjected to corruption due to external disturbances, because the distance they have to travel to reach the destination is greatly reduced. In this kind of system the operative procedures are recorded inside the single device that takes care of the elaboration of the information. This allows higher operating speed, because each task is rapidly satisfied locally, without the need for reaching the central system (and thus being exposed to transmission mistakes), without elaboration and back transmission. The installation cost is reduced too, because the points are locally connected to the controller through a relatively short connection. The only long connection is the communication network that allows the data exchange between the devices.

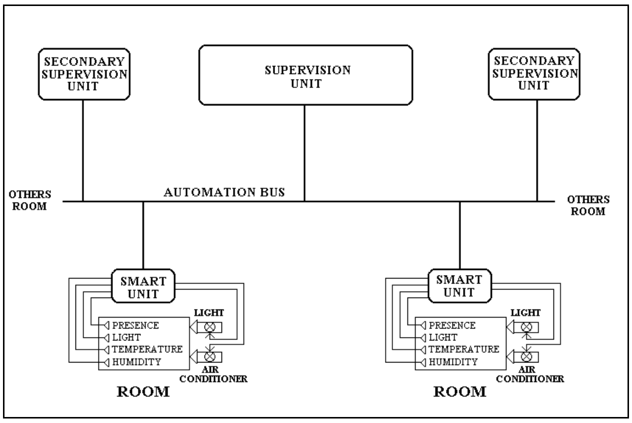

Figure 3.: Scheme of the distributed smart system.

2. THE CONTROLLING SYSTEM

We want now to describe the architecture of the used system. Since we use a distributed smart system, ours is composed by a certain number of micro computerized modules (MCM) connected to each other by means of a communication network. We first analyze the typical structure of the MCM, the communication network and finally the acquiring sensors. The MCM is a micro computerized module appropriately miniaturized on a printed circuit board, equipped with a microprocessor, a random access memory (RAM) and a read only memory (ROM). The MCM is built using low energy consumption CMOS technology. This feature allows the module to work even in the absence of the main electrical power source, using an auxiliary battery. The typical power consumption is of about 2 watts. Further, to avoid malfunctioning or loss of memory due to electrical disturbances or spikes, that would unavoidably compromise the data stored in the RAM, this component of the system is provided with a back-up on-board battery that ensures the memory always has a stable supply, even in the absence of the main energy supply. Further, the MCM is equipped with a serial electrical erasable serial programmable read only memory (EEPROM) that is a particular kind of memory with the interesting feature of being written in a random way, such as found in RAM memory, and of storing the data indefinitely, such as found in ROM memory. In this kind of memory, important information can be stored, such as, for example, the calibration constants of the sensors, that cannot risk corruption and do not need to be changed continuously. In fact this kind of memory is quite expensive and therefore has a limited size (few hundreds of bytes), and due to its operative features, the writing cycle is slower compared to other memory technologies. But the most powerful features of the MCM is its capabilities of self-writing the main program in its EEPROM. This feature drastically reduces the start up work, since the program, once transferred on board, can be rapidly tested and eventually changed, as directed by the MCM and eventually changed directly by the MCM that can definitively store it in its EEPROM when it is completed. The traditional procedure, on the contrary, needs the program to be tested on a simulator computer, without a direct correspondence with input-output real situation, to be stored in an EPROM chip, by means of a rather expensive memory programmer.

Finally it is necessary to transfer manually the programmed chip on the MCM board exposing it to the risk of mechanical damage, due to bad pin insertion, or to electrical damage, due to electrostatic voltage. Therefore the MCM can be summarized as a low energy consumption composed by a 16 bit high computation power microprocessor, a ROM memory, where the operating system is stored, an EEPROM memory, where the main program is stored, a RAM memory, where the run time data is stored, and a serial EEPROM where data is stored which is not frequently changed. Further there are digital and analogue inputs and outputs, a communication port, a keyboard and a display interface.

The digital and analogue inputs-outputs are all opto-isolated through appropriate opto-modules. This feature allows the MCM to be totally separated from the electrical power that could damage it. For this pourpose the opto-modules are installed on a separate board that is connected to the MCM by means of a flat cable. In this way any connection error is avoided during the installation of the system. Its flexibility is due to the fact that the ports can be configured both as inputs or outputs, allowing the system to be reconfigured at any moment of its operative life. The writing-reading cycle takes about 100 nsec for digital port and 0.5 msec for analogue port.

The MCM is equipped with some buffered communication ports that allow a variety of network configurations. The buffer features of the port allows the microprocessor to be totally free from the task of controlling the communication since this work is done by a dedicated chip that:

- receives data from microprocessor,
- prepares them to be transmitted according to the desired protocol to the network as soon as it is available,
- decodes network data storing them in its internal buffer memory,
- advises the microprocessor that there are available data in the buffer.

The MCM is further equipped with a keyboard and display interface that allows any kind of desired input-output user operation.

Due to the high computation capability and to the configuration flexibility of the fundamental element of the smart distributed system, constituted by the MCM described above, it is possible to realize a high level management and control of energy flows that can be extended, without any extra cost, to other equipment such as an anti-thief system, a fire alarm system, a presence control system and so on.

2.1 THE PRESENCE SENSORS

The presence sensor is the first important element in our proposed system, since it allows the controller to know if there are persons inside the controlled room and consequently to act on the light and on the air conditioner installations.

The presence sensors to be used are those commonly used for security applications, of which we only consider ultrasound sensors, microwave sensors and passive infrared sensors, illustrating their disadvantages and their advantages.

The ultrasound and microwave sensors belong to the family of active sensors, since they generate an energy field that is used to reveal the presence of persons. The passive infrared sensors, on the contrary, belong to the family of passive sensors, that is they respond to variations in the received infrared emission caused by the presence of a person.

The effect used in the ultrasound and in the microwave sensors is the Doppler shift, which implies that they are more sensitive to frontal motions than to transverse motions.

The infrared sensor, in contrast, is equipped with an optical device, typically a Fresnel lens or an optical reflector, that divides the optical controlled field into different zones. The presence of a person is detected by checking the infrared variations in the same zone or between different zones, so the infrared sensor is sensitive to frontal or transverse motions, making it more suitable for our application. Further, since it does not generate any active field, it is characterized by a low energy consumption, making it useful for continuous use.

A disadvantage of ultrasound sensors is that they are sensitive to environmental noise, while a disadvantage of microwaves is that they are capable of passing through non metal objects, that is they can generate a presence signal revealing presences in a nearby room even if there is nobody inside the controlled room.

Passive infrared sensors, on the contrary, strictly reveal infrared variations in the controlled room. The only disadvantage is that they are sensitive to heat sources, even if they are well shielded from non human infrared wavelengths, that is out of the interval 8-12 μm.

They have therefore been shown to be the best candidates for this kind of application, provided that they are installed with the precaution of avoiding heat sources such as direct sun light, fires and heaters in their optical field. This can generally be done by changing the installation wall.

The typical coverage area is variable between 3 and 15 meters, covering the most of applications. The spread coverage angle varies between 120° (wall mounting) and 360° (ceiling mounting).

It is anyway possible to choose different characteristic infrared sensors for particular coverage areas.

2.2 THE LIGHT SENSORS

The first controlled energy flow is the light system. We first describe the acquiring sensor discussing the reasons that lead to choose a particular light sensor rather than the alternative. The most common low cost light sensors commercially available is the photoresistor. It is a particular sensor composed by two electrodes separated by a photo-sensitive component such as ZnS. This material has the property of varying its resistivity according to the intensity of the light that is received. The resistance variation range for a typical commercial device is very wide since it varies from few tens of ohms at some thousands of lux to few megaohms in total darkness. The variation law is typically non linear.

Thanks to the high computation capability of the MCM it is possible to give to the module a few calibration points, and let it calculate, through an appropriate interpolating algorithm, the right values of light intensity.

2.3 THE LIGHT CONTROLLER DEVICES

We want now to describe the light controller device. Different circuits are available to alter the light intensity of a lamp, which have different features and obviously different costs. Since the light sources considered here are only incandescent, fluorescent and dichroic lamps, whose intensity strictly depends on the applied voltage, it is possible to control them accurately by controlling the voltage applied to them, with some exceptions and precautions which we will deal with later. The most common low-cost technique used to control the voltage of an alternate source is phase control. It succeeds, given a sinusoidal voltage, in controlling exactly the phase delay, through an appropriate switching mechanism, to supply the desired electrical charge. The phase switching is activated each semi period of the sinusoidal voltage supply. It is evident that the medium square value of the voltage is totally applied to the charge if the phase delay is equal to zero, and decreases with the phase-delay φ according to the following law:

$$\bar{V}^2(\varphi) = V\sqrt{\frac{1}{\pi}\int_{\varphi}^{\pi}(sin(t))^2 dt} = V\sqrt{\frac{1}{2} - \frac{\varphi}{2\pi} + \frac{sin(2\varphi)}{4\pi}}, \quad (1)$$

where V is the amplitude of the voltage and φ the phase-delay.

The best linear response of the voltage as a function of the phase is in the central zone of the phase interval: this is rather intuitive owing to the sinusoidal behavior of the input voltage that grows faster in the central zone.

This technique can be used without any inconvenience in light sources that can tolerate sudden voltage transition such as the one that takes place when the switch changes its state from off to on. This is not a problem for the three considered kind of lamps. The only secondary effect presented by the incandescent and dichroic lamps is the change of the spectral emission towards the red zone of the visible spectrum due to the lower temperature of the filament of the bulb as the voltage is reduced.
The phase-control technique, due to the previously mentioned rapid switch-on and off, generates a large number of harmonics that could create electromagnetic compatibility problems if they are not properly shielded. Even if the dimmer is well shielded it would be recommendable to position the device as close as possible to the lamps to be controlled, so that any residual disturbances do not radiate through the antenna effect shown by the long connection wires. In this way there could be some problems owing to the fact that, the more the connection between the dimmer and the lamps is shortened, the longer is the connection between the MCM and the dimmer, exposing the MCM to the risk of damage. This inconvenience is not present in the MCM used here thanks to the opto-isolated inputs and outputs.

We want now to discuss the stability of the controlling mechanism. In fact, due to the presence of a feedback loop constituted by the chain "sensor → controller → actuator", it is necessary to ensure that a certain desired value of the controlled parameter is maintained even in the presence of external disturbances. The stability theory of this kind of system would be too long to be studied in this paper. We only briefly mention a practical criterion that guarantees the well-being of the users of the controlled zone, based on the speed of variation of the desired parameter. In fact it is well known that the more slowly a parameter varies, the more comfortable is the environment. See for example the situation where a room has reached a too high temperature that is out of the comfort range: in this situation a sudden decrease of several degrees, aimed at ensuring the correct temperature, is felt as a discomfort, even if the final situation is the correct one. That is to say that each environmental parameter such as light, temperature, humidity and so on, has its own optimal variation velocity that cannot be exceeded without generating a sensation of discomfort.

In our case, the speed of the loop "energy flows → effect → sensor → controller → actuator" strictly depends on the physical features of the considered phenomenon that is the binomial "energy flows → effect", since the remaining part of the loop is characterized by electronic speeds except for the actuator. In fact while in the case of light the speed of the binomial “energy flows $\rightarrow$ effect” is very fast since any variation of the intensity is immediately read by the sensor, in the case of the air conditioner this speed is very much slower due to the intrinsic features of the phenomenon.

In the light case it is demonstrated that a variation speed of 10 lux/sec is the maximum tolerable variation that does not provoke discomfort. The delay time of the loop in this case can be ensured both by the controller or by the actuator, depending on the project choice. It is anyway preferable to let the MCM control the delay time using an actuator which is as fast as possible, so that it is possible to vary, without any restriction, the variation speed at any time.

2.4 THE TEMPERATURE SENSORS

We want now to describe the sensor and the actuator used to control the other important energy flow that is the air conditioner. The sensors considered are thermo-resistances and integrated sensors. The thermo-resistances are appropriately constructed resistances whose values can increase (PTC or positive temperature coefficient) or decrease (NTC or negative temperature coefficient) with temperature. The variation law is typically non linear. The same considerations we made about the photo-resistances are valid for thermo-resistances. The other kind of sensor considered here is the temperature sensor. These devices are particular integrated components that generate a voltage proportional to the temperature. The temperature gradient is generally equal to 10 mV/°C. Considering a sensor built to work in the range 0-100 °C, we have an output voltage of 0 V at 0 °C and an output voltage of 1 V at 100 °C. These sensors, thanks to their robustness and to their optimal output voltage are very interesting for use in these kinds of applications.

2.5 THE AIR CONDITIONER ACTUATORS

The actuator devices used depends on the kind of devices to be controlled. If a traditional heater is present, it is necessary to use an electric valve that opens or closes the hot water flow inside it. If a fan coil is present there are two controlling possibilities: step control or continuous control. The step control uses a discrete number of velocities of the fan while the continuous control varies the fan velocities in a continuous range according to the needs. This last control is generally more expensive in comparison with the other one since it is necessary to use a proper controller device for the velocity of the fan. The step control, on the contrary, just changes the velocity of the fan using the switch already present in the fan coil, representing a valid compromise between efficiency and cost. In fact, due to the relevant inertia of the heating effect, it is not necessary to use a precise and fast control of the heater source.

Due to the low velocity of heating processes, it is not generally necessary to introduce a delay time in the MCM to slow down the operative speed of the loop, to avoid instability. It is anyway convenient to introduce more refined control mechanisms rather than the simple on-off, as for example a simple hysteresis.

2.6 FURTHER DEVELOPMENTS

Thanks to the use of sensors of presence, it is possible to know, at every moment, how many persons are in the house and where: this means that it is possible to use the system as an anti-theft system that is activated when nobody is inside the house, without any further cost.

At this point it is evident that, thanks to the high computation capabilities of the system considered, it is possible to realize a very useful energy flow controlling system that ensures a high level of energy saving and an improved comfort of the house where it is installed.

In fact the system can be programmed to satisfy any exigencies and needs. It is possible for example to turn the light off after a certain time that a room is left empty. Since the MCM is equipped with a clock on board, it can memorize the time and the frequency of these situations and calibrate its turn off action according to these. It can further trim exactly the light intensity according to the light entering from the window, so that the average intensity is constant. In this way it is possible to avoid any intensity gradient that would disturb the occupants and it avoids energy waste.

The system can shift the turning-on time of the air conditioner according to the daily environmental conditions. Similarly it changes the turn on and off time according to the memorized and refreshed occupation time of each single room. In this way each room can have its own exact level of temperature and humidity.
Plenty of ideas and procedures can be realized using this system and we could say that the only limit is fantasy!

3. CONCLUSIONS

We have illustrated a scheme of a system to control the energy flows in a building. We have demonstrated that a high quality of control can be attained if a distributed smart system is used. Thanks to its peculiar features it is possible to provide other important services such as anti-theft systems, anti-fire systems, presence controls and so on.

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