Chapter 2
A Case Study: The CDdI-CIESOL-ARFRISOL Building

Abstract This chapter is intended to give a complete description of the bioclimatic CDdI-CIESOL-ARFRISOL building which has been used to test the developed control systems. Therefore, in this chapter several bioclimatic approaches are presented as well as the computer application in charge of supervising and controlling the building.

2.1 Introduction

The CDdI-CIESOL-ARFRISOL building, see Fig. 2.1, is a solar energy research centre located inside the Campus of the UAL in the south-east of Spain. It is distributed into two different floors with a total surface of 1,071.92 m^2. As can be observed in Fig. 2.2, this CDdI is composed of six offices, all of them facing east and located on the ground floor, with the exception of the main office which is located on the upper floor, eight laboratories which face north (four located on the ground floor and devoted to *Solar Chemistry*, and the other four are situated on the upper floor, two for the *Modelling and Automatic Control unit*, and the remaining for the *Evaluation of Solar Resources unit*), a plant where a high efficiency boiler and an absorption machine are located, and finally, rooms for employees of the centre such as the kitchen and the toilets.

The building was built following several bioclimatic criteria that affect its architecture, such as the use of an HVAC system based on solar energy (Pasamontes et al. 2009). This HVAC system makes use of a solar collector field, a hot water storage system, a boiler and an absorption machine with its refrigeration tower, in order to produce hot or cold air as a function of the demanded necessities. In addition, the building enclosure is different as a function of the orientation, for example, in the north and west facades the enclosure is composed of an external wavy sheet, isolation and a thermo-clay block which provides greater isolation in comparison to the construction materials normally used. On the other hand, the south and east facades consist of a ventilated facade with external ceramic tiling, a wall cavity, polyurethane

M. Castilla et al., *Comfort Control in Buildings*,
Advances in Industrial Control, DOI: 10.1007/978-1-4471-6347-3_2,

Fig. 2.1 The CDdI-CIESOL-ARFRISOL building

insulation and an internal wall of high thermal inertia. This kind of enclosure of high thermal inertia combined with the appropriate use of thermal insulation, produce a delay in the indoor environmental conditions in relation to the external ones, and moreover, they are able to buffer daily indoor temperature fluctuations inside the building.

Another applied strategy has been the setback of the windows which face south and east to avoid the direct influence of solar radiation in hot months, and allow the input of radiation in winter, see Fig. 2.3. Furthermore, the roof of the building has been shaded in two different ways in order to avoid the direct effect of solar radiation. In the following sections all these strategies are explained in detail.

2.2 Assumed Strategies/Actions

As was mentioned previously, the building was built based on different bioclimatic architecture criteria. Thus, it includes several passive strategies which allow to make the most of the environmental characteristics of the site where the building is located, and other active strategies which make use of renewable energies, such as the HVAC system based on solar cooling.

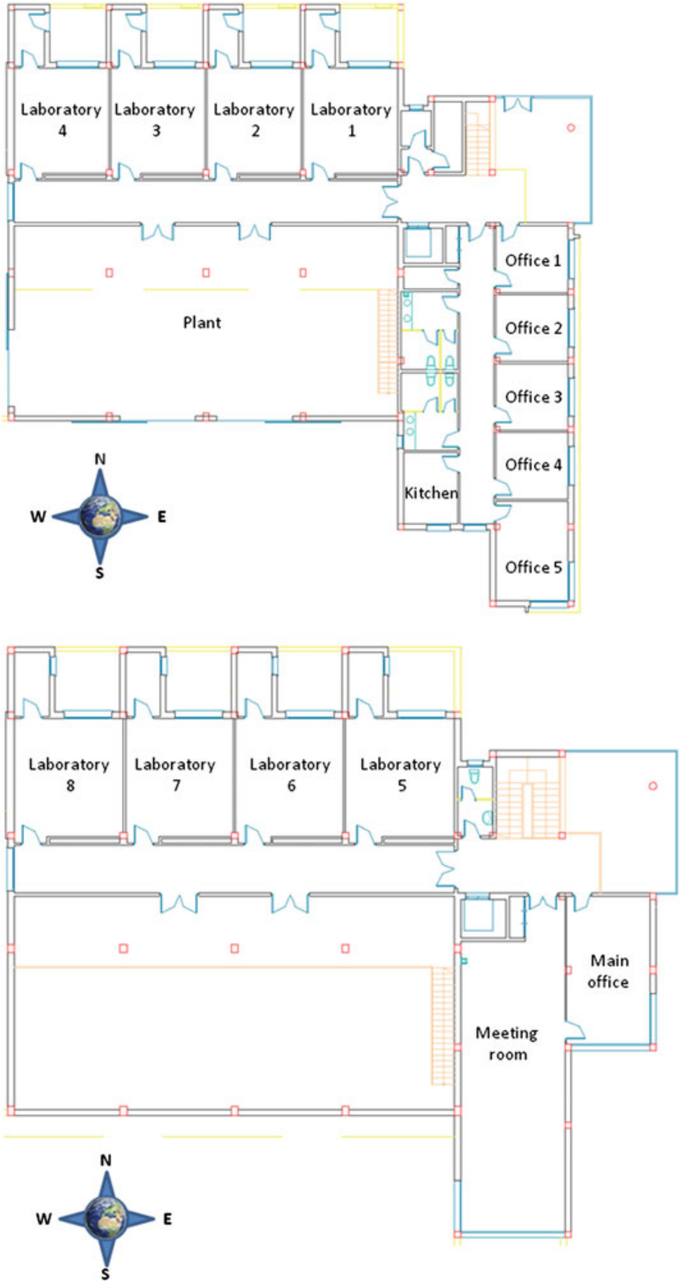

Fig. 2.2 Ground (*top picture*) and upper (*bottom picture*) floor schemes of the building

Fig. 2.3 Setback of east and south faced windows of the building

2.2.1 Building Enclosure

One of the most important factors in a building is its enclosure, since the solar gathering process is performed through it. In general, in a building two different kinds of enclosures could be considered, glazed and opaque.

The first enclosure is the element responsible for the most part of solar gains, since it is through it that the process of solar gathering has the most influence (Bosqued et al. 2008). Therefore, the design of glazed enclosures is a key factor both to prevent (a correct selection of its orientation) and at a corrective level (selecting the suitable type of glass). In the case study of this building, both a climatic double thermoacoustic piece of glass (CLIMATIC 2013) and security glass, with aluminium frames, have been selected.

On the one hand, and in contrast to the glazed enclosure, the heat flow through an opaque enclosure is not instantaneous, since it arrives indoors with a certain absorption and time lag. In the studied building, different external enclosures have been selected as a function of their orientation and use. More specifically, the south and east facades present an enclosure that consists of a ventilated facade which is composed of a quoted perforated brick, a 3 cm thickness sprayed polyurethane foam insulation, a wall cavity, and a compact ceramic tiling (Bosqued et al. 2008). On the other hand, the enclosure of the plant and the north facade is composed of a 20 cm

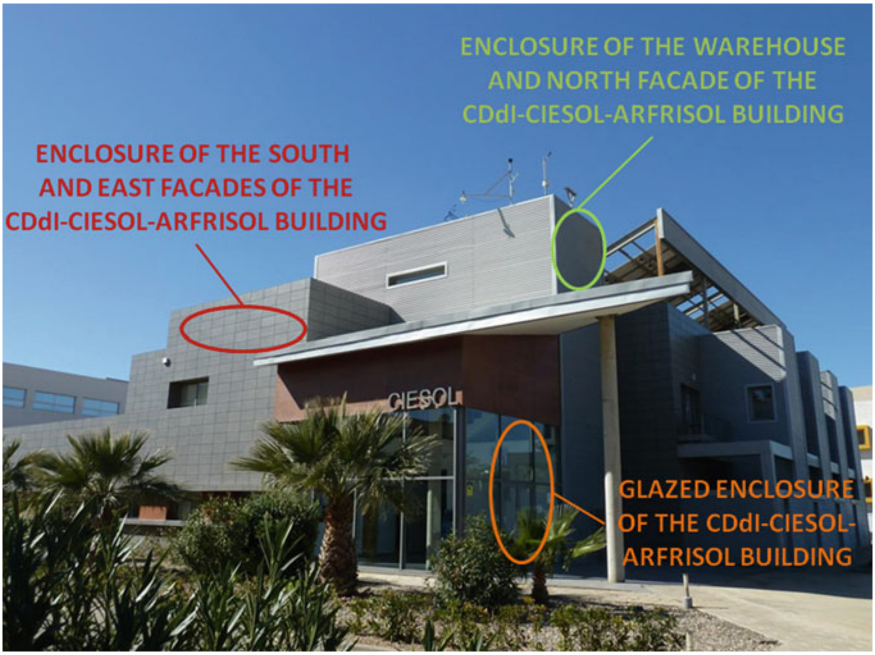

Fig. 2.4 Outside enclosure of the building

thick thermo-clay block, a 3 cm thick sprayed polyurethane foam insulation and a covering of galvanised steel wavy sheet (Bosqued et al. 2008), see Fig. 2.4.

2.2.2 Roof Shading

The location where the building is situated is characterised by a typical subtropical semi-desert Mediterranean climate with an annual average number of 2,965 h of sunshine (climate values registered at the meteorological station of the Almería airport, situated a 3.5 km far from the building). For this reason, it is recommended to use strategies able to soften the effect of solar radiation. One of the most appropriate techniques to solve this situation is the installation of shading elements. In general, within the building construction there are two different shading elements, outdoor and indoor ones. The outdoor element avoids the incidence of solar radiation inside the building before its proceeds through the glazed areas. Some examples of outdoor shading elements can be cantilevers, vegetable facades, etc. On the other hand, indoor protections are responsible for reducing the effect of solar radiation once they go through the glazed areas, like blinds and curtains.

In the case of the analysed building, all the windows located in the south and east facades are equipped with Venetian blinds, which can be regulated in orientation and

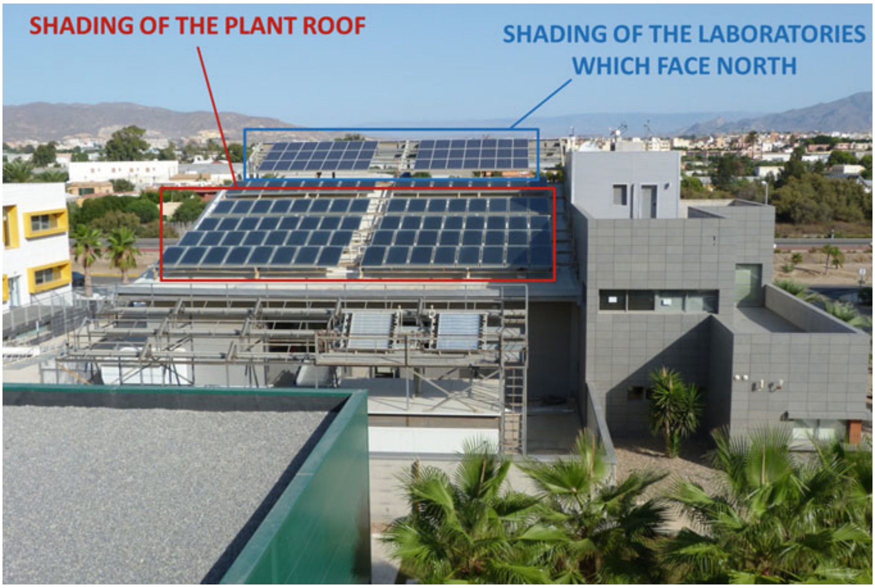

Fig. 2.5 Shading of CDdI-CIESOL-ARFRISOL building roof

height. In addition, the plant and laboratory roofs have been shaded using thermal solar panels for solar cooling installation, and photovoltaic panels to produce energy, see Fig. 2.5.

2.2.3 *Natural Ventilation*

Natural ventilation is one of the most used techniques in natural refrigeration. It tries to use outdoor air to dissipate the excess heat inside of the building. To produce air movement inside the building there are different strategies: simple ventilation, crossed ventilation, wind stack, wind towers, *Tromble-Michel* walls, solar stack, solar-air collectors, halls, etc. (Bosqued et al. 2008).

In this case, a crossed-ventilation strategy has been adopted (originated by means of wind forces) for the passive fitting-out of the plant through the hottest months. Crossed-ventilation is obtained throughout the opening of grilles in the doors located on the south wall of the plant and on the upper contrary face, looking north. With this, it is intended to refrigerate the plant by taking advantage of the south–north orientation and the configuration of the inclined roof (Bosqued et al. 2008).

Fig. 2.6 HVAC system based on solar cooling: absorption machine and hot water storage system

2.2.4 Solar Cooling Installation

The building has an active HVAC system based on solar energy and it is composed of a solar collector field, a hot water storage system, a boiler and an absorption machine with its refrigeration tower, with a total cooling power of 70 kW, see Fig. 2.6.

Moreover, Fig. 2.7 shows a scheme of the solar cooling installation, where three main circuits can be observed: the primary, on the left, is responsible for providing the necessary energy for the HVAC system. The secondary, on the right, is in charge of flowing cold water (in summer) or hot water (in winter) to the different fancoil units distributed all around the building. Finally, there is a third auxiliary circuit which is responsible for connecting the absorption machine with the refrigeration tower.

Under ideal conditions, the HVAC system has the following behaviour (Pasamontes et al. 2007a): the water flows through the solar collector field rising its temperature. This hot water goes into the absorption machine, which refrigerates the water adequately, and thus, it is injected into the fancoil system with the main objective of covering the temperature necessities of the environment where this service is demanded.

On the other hand, and mainly as a function of environmental conditions, it could be impossible using only the solar collector field, to heat enough the water so that

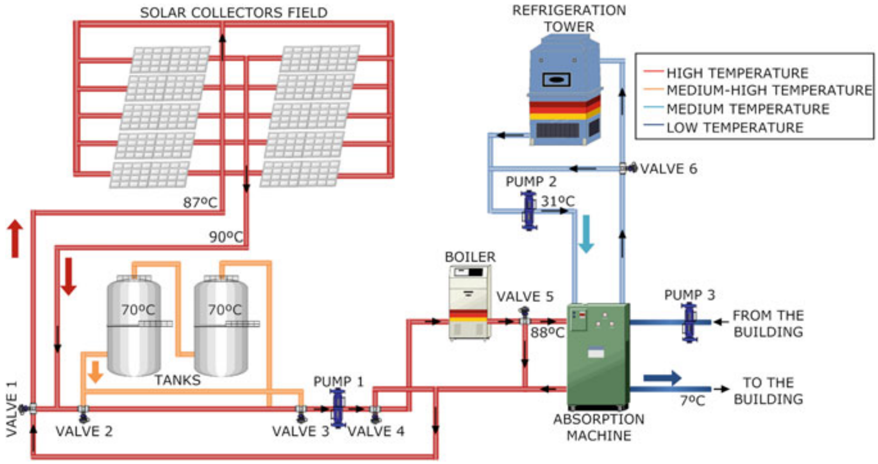

Fig. 2.7 Operation scheme of the HVAC system based on solar cooling

the absorption machine can chill it, since it needs a specific water temperature input in order to work properly. For this reason, the use of a hot water storage system and a boiler is justified. The hot water storage system is composed of two tanks of approximately 5,000 L each. Moreover, they are thermally isolated in order to maintain the heat of the stored water and, in this way, when the system is free and the solar radiation can be useful, the hot water generated by the solar collector field is stored in these tanks. Finally, although the main objective of the solar cooling system is to minimise the use of auxiliary energies, the boiler is used to provide the necessary power under any environmental condition in order to supply the correct service to the users of the HVAC system. Furthermore, it can be used alone, or to heat the water which comes from the hot water storage system or the solar collector field until the appropriate temperature for the absorption machine is reached.

2.2.5 Summary

Once the main bioclimatic strategies have been explained and to conclude this section, a brief description of the behaviour of the whole building is given as a function of the period of the year and the influence of each one of the strategies commented previously. In a first approximation, the behaviour of the building along the winter season is explained. For this, and according to Fig. 2.8, the incident solar radiation (see yellow lines) is used to heat the solar collector field placed on the roof of the plant and the interior through the windows located in the south facade. At the same time, hot water from the solar collector field flows through the fancoil units and is distributed through the whole building heating each one of the different environments (see red lines).

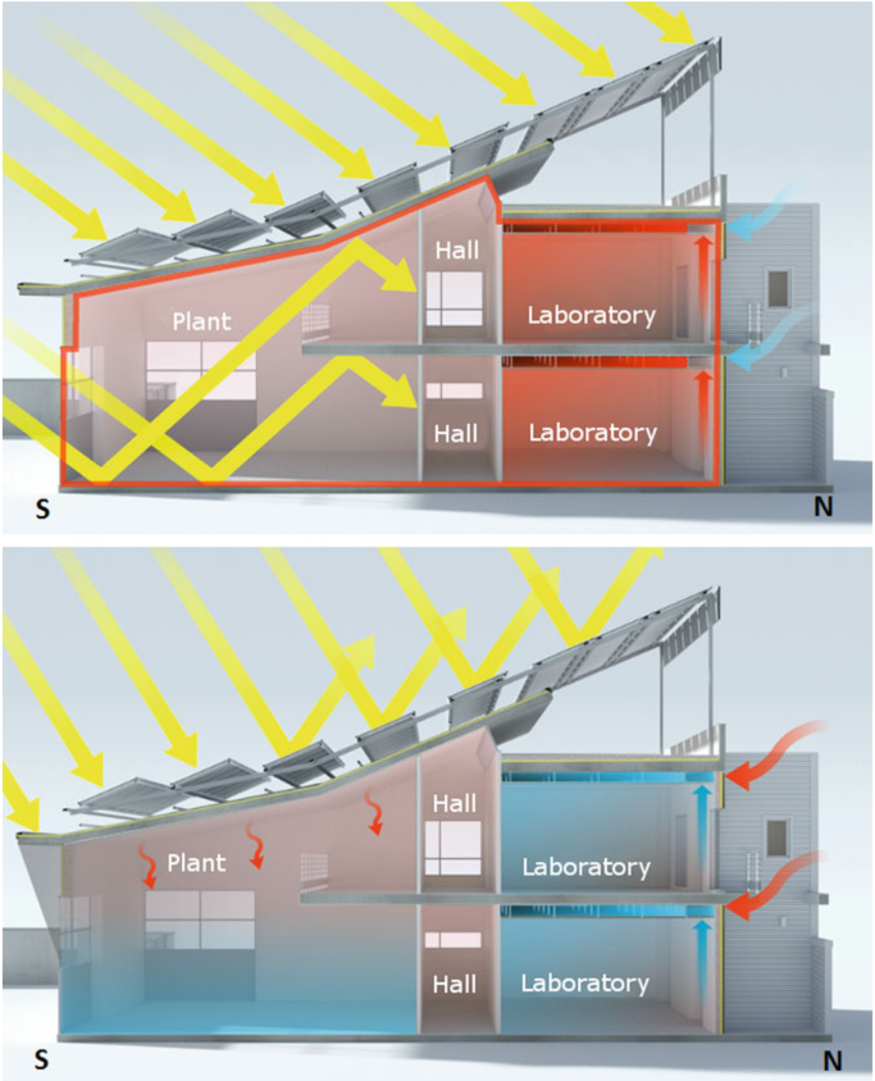

Fig. 2.8 Behaviour of the assumed bioclimatic strategies along the winter season (*top picture*) and the summer season (*bottom picture*) (PSE-ARFRISOL 2013)

Additionally, in the summer season, see bottom picture in Fig. 2.8, the slope of the solar collectors and photovoltaic panels fields avoid the direct influence of the solar radiation on the roof of the building acting as a shading system (see yellow lines). Besides, hot water from the solar collector field circulates through the absorption machine becoming chilled water, which is used to cool the building by means of fancoil units. Finally, throughout the night the appropriate mechanisms are active in order to refrigerate the building by means of crossed-ventilation as mentioned previously. Finally, Fig. 2.9 shows a summary of the different considered bioclimatic strategies.

2.3 Sensors and Actuators Network

In order to analyse the compliance of the established objectives within the framework of the PSE-ARFRISOL and POWER research projects, it is necessary to have a wide network of sensors and actuators, and an appropriate data acquisition and measurement system. The availability of these data, will allow the researchers to understand the behaviour of each one of the bioclimatic strategies implemented in this building, and also, the energy saving and CO_2 emission reduction which can be obtained with them.

In this section, a summary of the selected transmission network, its main characteristics and its distribution all around the building is presented. In addition, a general description of the main sensors and actuators which are actually installed in the building is given, classifying them according to their location and usefulness.

2.3.1 Fieldbus Communication

When it is necessary to design a network of sensors and actuators inside a building with these characteristics, one of the most important points is to select the best type of communication technology, bus or network, in order to communicate in an appropriate way with sensors and actuators. To do this, several strategies with different characteristics and based on distinct ways (both wireless and wired) were studied. Initially, the considered technologies were (Pasamontes et al. 2007b):

- Wireless transmission. HomeRF (v1 and v2), WiFi and HIPERLAN, ZigBEE and WIMAX, and secure connection by means of TCP/IP through Ethernet.
- Wired control. X10, EHS (European Home System), SimonVIS, BatiBUS, CEBus, EIB, KONNEX, LonWorks, secure connection by means of TCP/IP through Ethernet.

For each of the previous alternatives, a detailed analysis and evaluation was performed as a function of the following factors:

- High availability of data. This specification was selected mainly due to the existence of processes in which dynamic control or the necessity of obtaining data from the environment is a critical factor.
- Acquisition and monitoring software developed in LabVIEW® (Medina 2002) of National Instruments which is a software of specific purpose as will be described in Sect. 2.4. However, this specification should not be considered a critical point,

Fig. 2.9 Bioclimatic strategies of the CDdI-CIESOL-ARFRISOL building

Fig. 2.10 Compact Fielpoint installed inside the building

since the majority of manufacturers have specific drivers for this software mainly due to its importance in the market.

- High security in the communication network access and robustness. This factor was the main reason that most wireless technologies were dismissed.
- Highly scalable.
- Maximum transmission distance without using relays.
- Maximum/minimum number of nodes allowed.
- Legal aspects. When the WiFi networks were analysed, the main legal aspects were studied in order to dismiss those whose specifications were not regulated in Europe.

After finishing this analysis, the alternatives were reduced to two different options: wired Ethernet or LonWorks bus. Finally, the first one was selected, since it satisfied the necessities of scalability, transfer rate and security. On the other hand, although LonWorks is ideally designed to be used within the automatic control area at a domotic level, the precision in data acquisition from the sensors is not comparable to that which can be provided by Ethernet, which is ideal for the necessities of research considered within the framework of the PSE-ARFRISOL and POWER projects.

Then, the most suitable acquisition technology was selected as a function of the development tool (LabVIEW®) and the specifications to satisfy. After a detailed study of the distinct alternatives available in the market, the *National Instrument* modules known as *Compact FieldPoint*, see Fig. 2.10, were selected. They consist of an industrial embedded platform which combines the best characteristics of a computer with the reliability, robustness and distributed nature of a programmable machine (Pasamontes et al. 2007b).

Finally, and based on the necessities of measurement inside the building, several acquisition modules, such as the one shown in Fig. 2.10, have been physically distributed by means of an Industrial Ethernet network all around the building. More specifically, the indoor plane of the building has been split into different zones considering several measurement cores, see Fig. 2.11. Each one of these cores is responsible for the connection of a sensor set to the Ethernet network in order to be made available from the acquisition and monitoring centre. The communications network architecture inside the building can be observed in Fig. 2.12.

2.3.2 Sensors: Description and Location

The building has a wide network of sensors installed all around the building. This network can be divided into four representative blocks, which are gathered according to the location and the main purpose of each of the sensors.

- Sensors inside the building.
  As can be observed in Table 2.1, inside the building there is a huge variety of different kinds of sensors with a total of 161 measurements. Most of these sensors have been installed to analyse users' comfort inside different environments of the building. To do that, five characteristic environments of the building were selected (two offices, two laboratories and the meeting room), and inside them a wider network of sensors was installed, see Fig. 2.13.
- Sensors in the meteorologic-radiometric station.
  The building has a meteorologic-radiometric station placed on the roof of the building, see Fig. 2.14. It includes a large amount of sensors which are detailed in Table 2.2.
- Sensors in the ventilated facade.
  As can be observed in Table 2.3, the zone with the highest sensor concentration is the ventilated facade. This zone, which has been selected to analyse the thermal behaviour of this kind of enclosure, is located in the southern facade of the building. The ventilated facade includes a huge set of sensors gathered at different heights and depths. More specifically, it has temperature and thermal flow density sensors at different planes and heights. In addition, it also contains air velocity sensors at different heights which are placed in the wall cavity. Moreover, in the external surface of the ventilated facade there are global and infrared radiation sensors, and wind velocity and direction measurements. Furthermore, it also includes a temperature sensor set distributed in the wall cavity that allows to determine if the flow inside it is laminar or turbulent, see Fig. 2.15. Finally, on the other side of the wall, there is one of the offices selected as characteristic, and therefore it has an equivalent sensors set. In this way, both the behaviour of the ventilated facade and its effect on this office can be analysed.

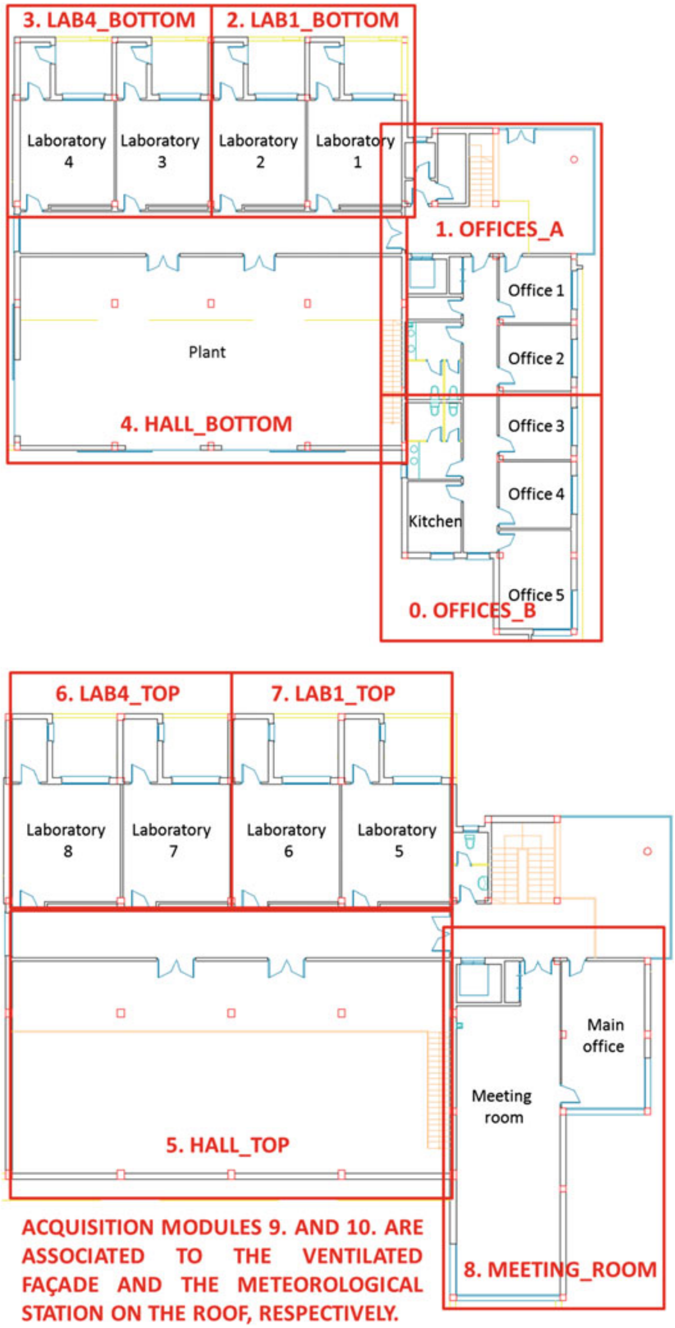

Fig. 2.11 Distribution of the acquisition modules inside the building

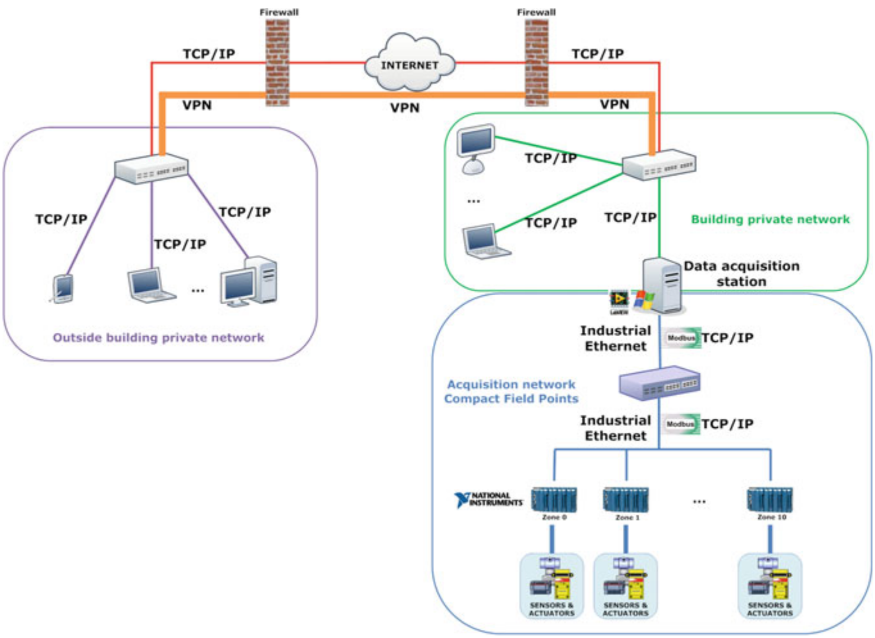

Fig. 2.12 Communication network inside the building

Table 2.1 Sensors inside the building (Ferre et al. 2010)

Measurement	Type of sensor	Number
Indoor air temperature	Thermometer	56
Plane radiant temperature	Surface thermometer	30
Glass surface temperature	Surface thermometer	4
Indoor relative humidity	Hygro transmitter	8
Indoor CO_2 concentration	CO_2 meter	6
Water temperature inside refrigeration circuit	Thermometer	12
Indoor air velocity	Hot-wire anemometer	3
Aperture/closure of doors	Contact sensor	19
Aperture/closure of windows	Contact sensor	9
Input/output of people	Photoelectric switch	8
	Total	161

- Sensors in the solar cooling installation.
  Finally, in Table 2.4, the large number of sensors installed in the solar cooling installation can be observed. A large part of these sensors are located in the plant, since most parts of the machines associated with the solar cooling installation (boiler, storage tanks, absorption machine, pumps, etc.) are situated there. More specifically, most of these sensors can be observed in Fig. 2.16, where a snapshot of the

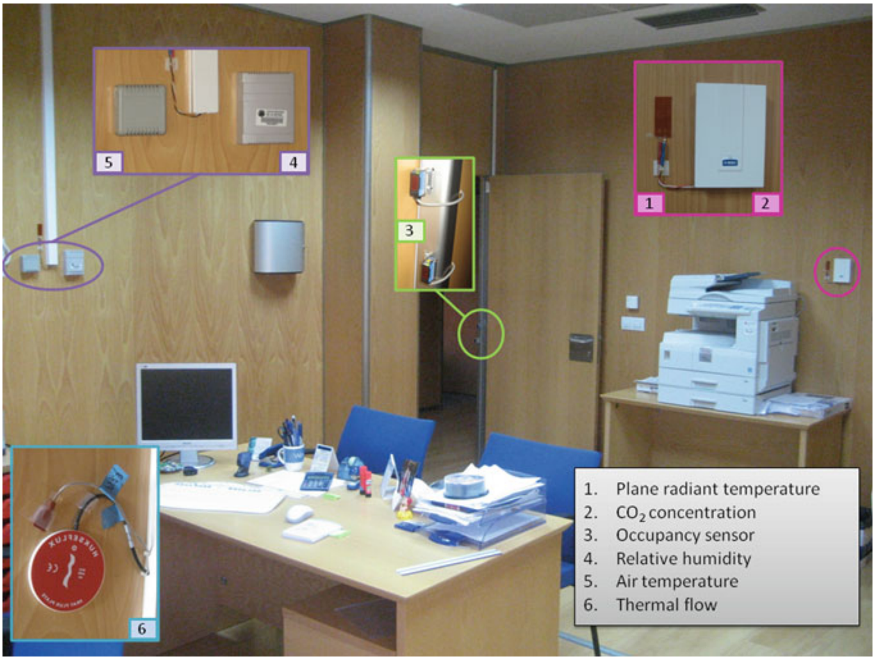

Fig. 2.13 Sensors inside a characteristic room of the building

main screen of the solar cooling SCADA system developed by Sauter (SAUTER 2013) is shown.

2.3.3 Actuators: Description and Location

In addition to the HVAC system based on solar cooling that has been widely explained in the previous sections, it was decided to automate windows and blinds of two characteristic rooms, in order to assay how these elements affect the active refrigeration and the illumination conditions. The selected rooms were the meeting room and one of the laboratories facing north. Windows are one of the most important elements since they affect the use of energy from different perspectives: (i) the exploitation of natural light instead of artificial lighting, (ii) they allow the use of shading devices, such as blinds, which can be used to control heat gains through it and (iii) they can be integrated into natural ventilation control strategies which can be translated into a reduction of energy consumption from HVAC system and an improvement of indoor air quality. As mentioned earlier, all the windows of the building have a climatic double thermoacoustic piece of glass and aluminium frames. In addition, Venetian blinds which can be regulated in both height and orientation were installed in the meeting

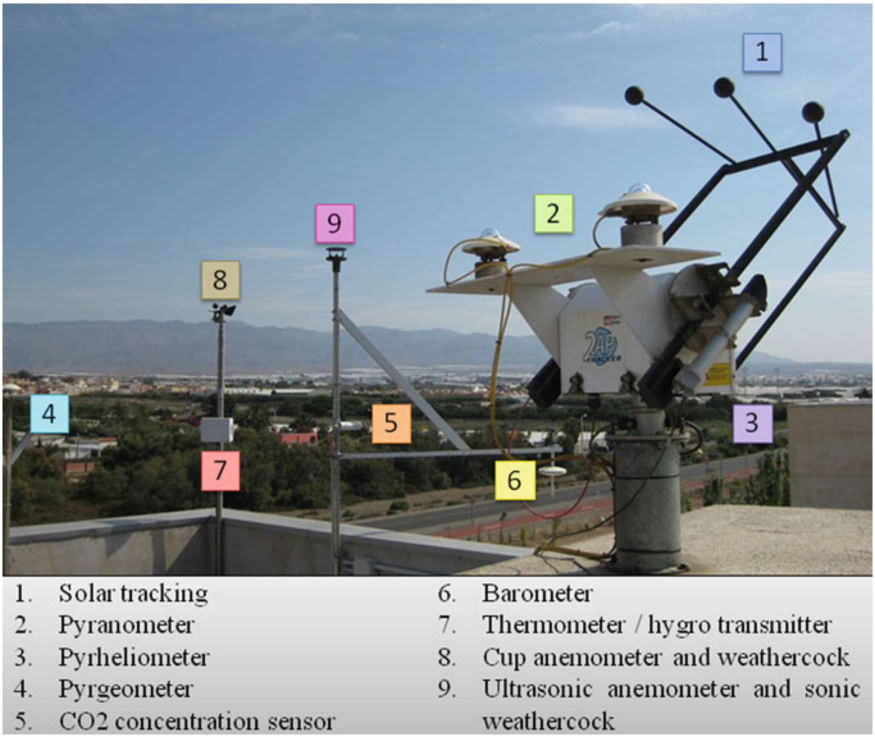

Fig. 2.14 Sensors in the meteorologic-radiometric station of the building

Table 2.2 Sensors in the meteorological station (Ferre et al. 2010)

Measurement	Type of sensor	Number
Global direct radiation	Pyranometer	1
Global diffuse radiation	Pyranometer	1
Direct radiation	Pyrheliometer	1
Infrared radiation	Pyrgeometer	1
Net radiation	Net radiation transmitter	1
Wind velocity	Cup anemometer	1
Wind velocity	Ultrasonic anemometer	1
Wind direction	Weathercock	1
Wind direction	Sonic weathercock	1
Air temperature	Thermometer	5
Relative humidity	Hygro transmitter	2
CO_2 concentration	CO_2 meter	1
Atmospheric pressure	Barometer	1
	Total	18

Table 2.3 Sensors in the ventilated facade of the building (Ferre et al. 2010)

Measurement	Type of sensor	Number
Vertical global radiation	Pyranometer	1
Vertical infrared radiation	Pyrgeometer	1
Wind velocity	Hot-wire anemometer	3
Wind velocity	Ultrasonic anemometer	1
Wind direction	Weathercock	1
Outdoor air temperature	Thermometer	1
Outdoor relative humidity	Hygro transmitter	1
Surface temperature	Surface thermometer	17
Air temperature in the wall cavity	Thermometer	12
Thermal flow	Thermal flow meter	2
	Total	40

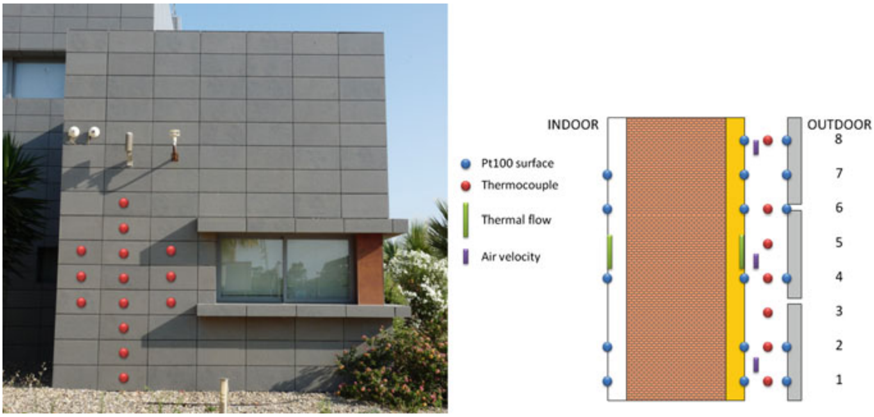

Fig. 2.15 Distribution of sensors in the ventilated facade of the building

room. Moreover, in the selected laboratory a solution based on vertical blinds was adopted.

To automate the windows, a detailed market study of linear motors was performed, and the *Olly-E* motor (Olly-E 2013) was chosen mainly due to its price-quality ratio and also because it is a versatile, silent and easy to install automatism for sliding doors and windows, see top picture in Fig. 2.17. On the other hand, for blind automation of the selected rooms, SOMFY motors (SOMFY 2013) for Venetian and vertical blinds have been used, see bottom picture in Fig. 2.17.

Table 2.4 Sensors in the solar cooling installation of the building (Ferre et al. 2010)

Measurement	Type of sensor	Number
Vertical global radiation	Pyranometer	1
Circuit temperature	Thermometer	74
Water flow	Flow meter	11
Inverter	–	4
Valve state	–	10
Power	Wattmeter	3
Gas consumption	Gas consumption meter	2
Relative humidity	Hygro transmitter	2
Air velocity	Anemometer	1
Other variables (valves' state, etc.)	–	412
	Total	520

The information related with sensors denoted by "–" is not available due to the commercial character of the solar cooling installation

2.4 SCADA System

The main objectives of the SCADA system are the validation of simulations, and the deviation analysis between the real and the simulated behaviour of the building, derived from the assumed hypothesis in its construction and other uncertainties. Other minor objectives of the SCADA system are:

- Data acquisition for its later analysis.
- Identification of users' bad habits with respect to the energetic operation of the building. In addition, it should be able to provide some recommendations about the use of the building, which will improve the rational use of energy.
- Comfort analysis. Relation between the obtained comfort degree and the energy consumption necessary to reach it.
- Effectiveness analysis of the passive conditioning strategies assumed in the building.
- Experimental study of singular components which present interest in reference to the implementation of energy saving strategies.
- Integration of the SCADA system with a control module for experimentation.

In general, SCADA systems are composed of several modules which allow to perform acquisition, supervision, analysis and control tasks (Boyer 2004). In the case of the building studied in this chapter, all these modules have been implemented according to international standards: ISA 101-Human-Machine Interfaces, ISO 9241 and UNE-EN 29241. Besides, these modules can be distributed in different computers without the necessity of having a centralised acquisition system, see Fig. 2.18. To develop each of these modules, LabVIEW® of National Instruments, a specific purpose software for such applications was used since it allows its users to provide an interface, to carry out communications and information management. However, for the implementation of control algorithms the software MATLAB® (Higham

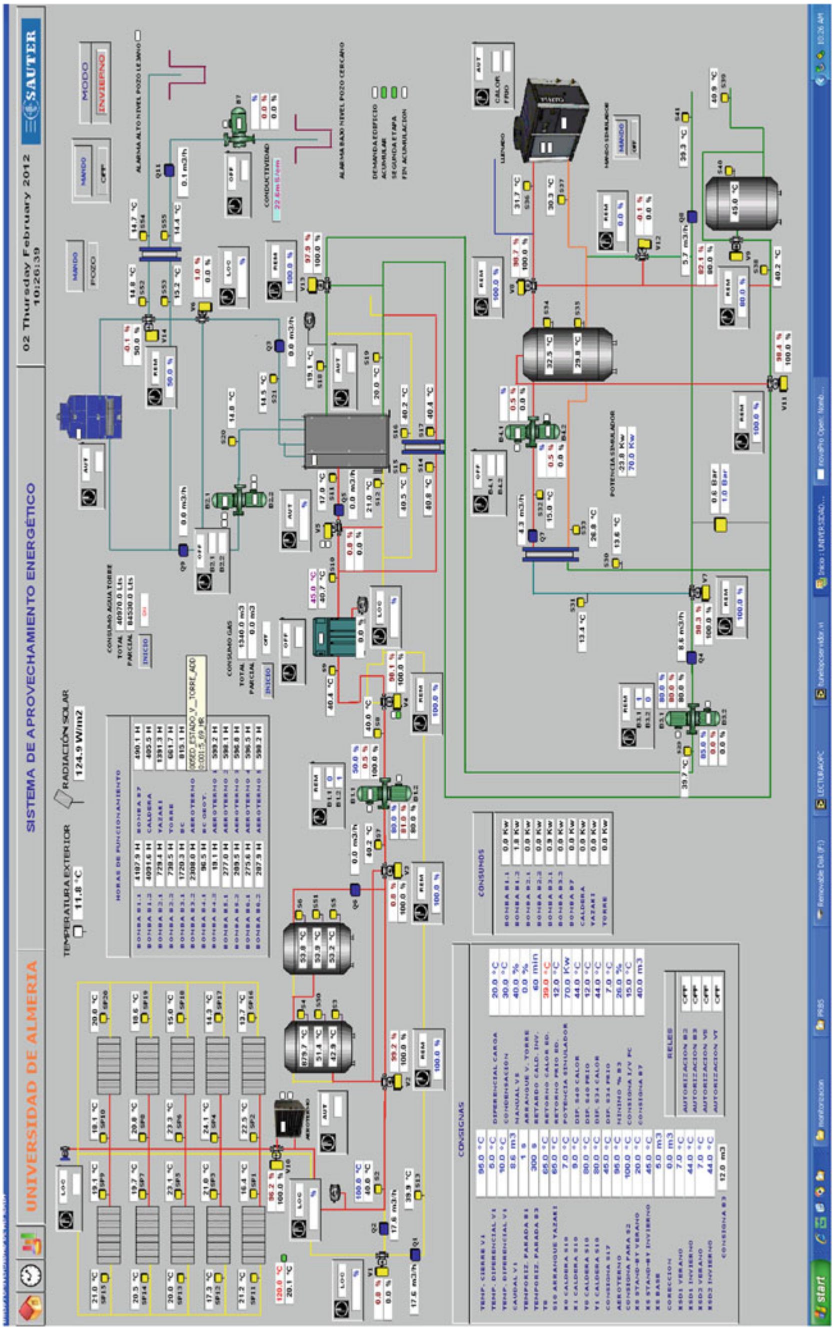

Fig. 2.16 Location of sensors in the solar cooling installation (labels in Spanish)

Fig. 2.17 Installed motors for the aperture/closure of windows (*top picture*) and blinds (*bottom picture*)

and Higham 2005) was used due to its mathematical power. As can be observed in Fig. 2.18, the building includes several Compact FieldPoints in order to collect data from the installation connected to the SCADA system developed with LabVIEW® by means of industrial Ethernet. On the other hand, the solar cooling installation has its own acquisition system developed by SAUTER (2013), that can be accessed by means of Object linking and embedding for Process Control (OPC), which is a communication standard in the industrial processes control and supervision area. Finally, to access the acquired data from outside the building, a connection through Virtual Private Network (VPN) with a computer inside the private network of the building can be established, and once inside it accesses the SCADA system that is used via Ethernet.

- **Acquisition module**
  This module is responsible for communication with the data acquisition modules (Compact FieldPoints) via industrial Ethernet. Hence, it performs data acquisition through connections to each one of the Compact FieldPoints which compose the system, and then, these data, acquired from different sensors, are stored in a database. Subsequently, through the use of an interface, these data are sent to the supervision module. Some of the main characteristics of this module are easy configuration of the channels and the addition of new sensors.

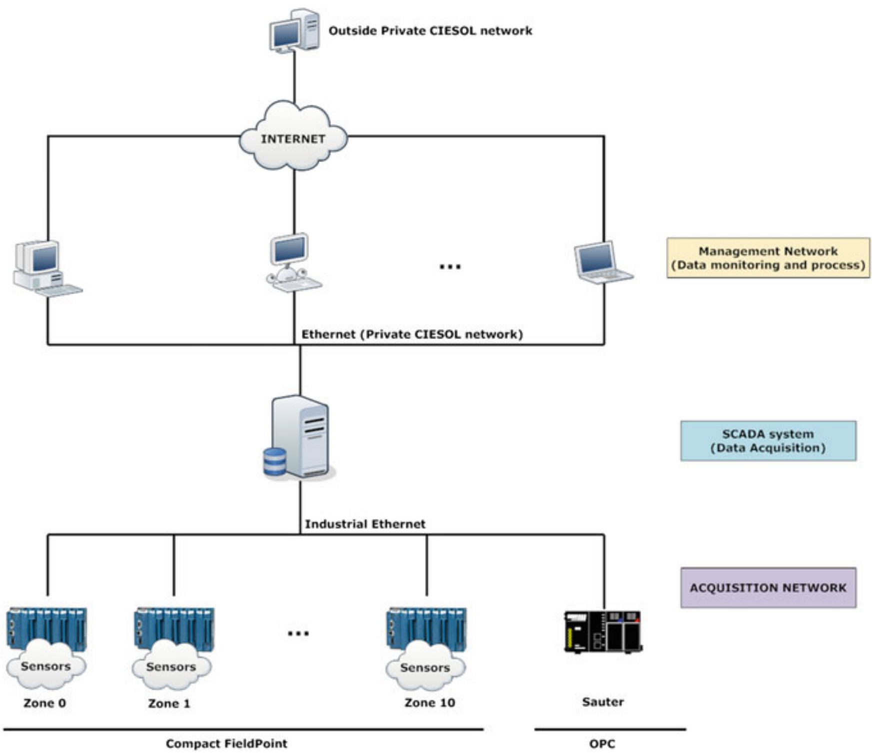

Fig. 2.18 Hardware architecture of the SCADA system

Moreover, this application performs a security verification for each of the acquired values before its storage in the database. This verification can be defined for each channel independently by the user.

- **Supervision module**
  The module of supervision performs visualisation of the acquired data by means of a friendly environment for the user of the system. To do this, several screens associated with each of the principal zones of the building have been designed, see Fig. 2.19. In each screen, the most important measurements of the zone are shown. Furthermore, in order to visualise these measurements in real-time, an interface able to connect the supervision module with the acquisition module was developed.
- **Data analysis module**
  This module is used to visualise historical data acquired and previously stored by the acquisition module. The main characteristics of this tool are that it provides an efficient way of historical data visualisation and filter and selection of certain registers. The visualisation of historical data is carried out through graphs where different sensor values can be observed in a quick and easy way, facilitating a first visual analysis. On the other hand, the filtering system of the application can detect

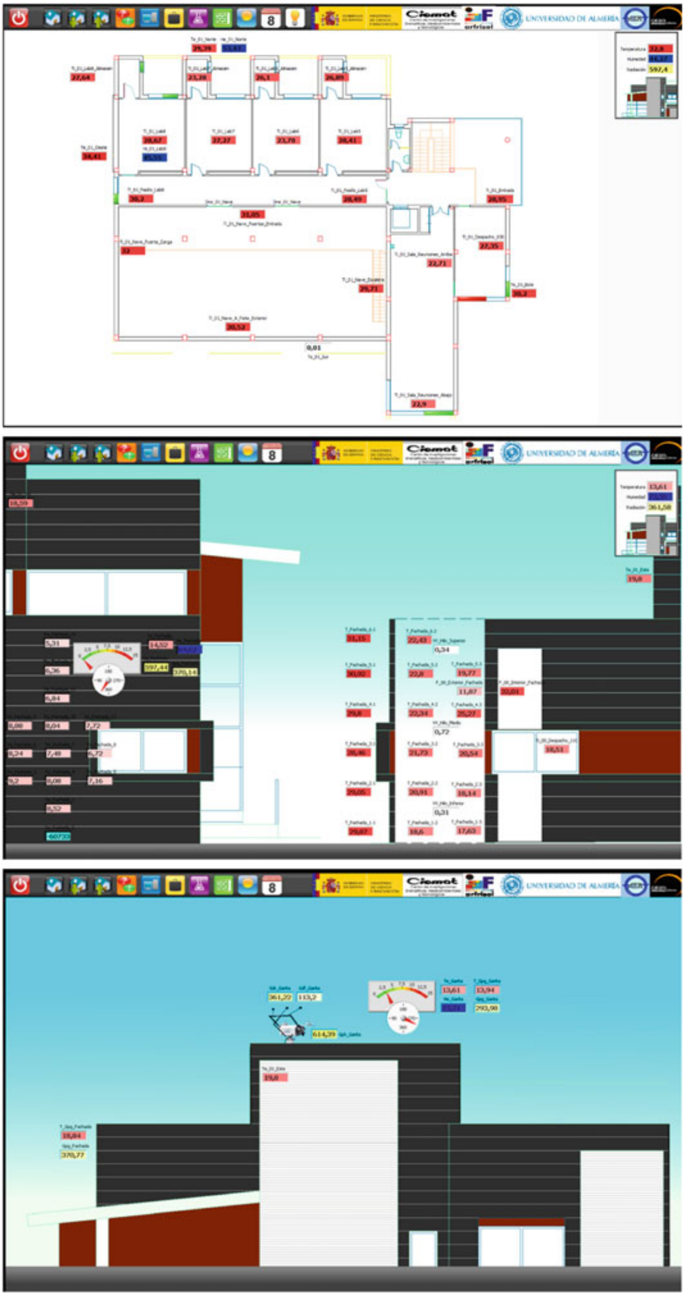

Fig. 2.19 Screens of the supervision module (labels in Spanish)

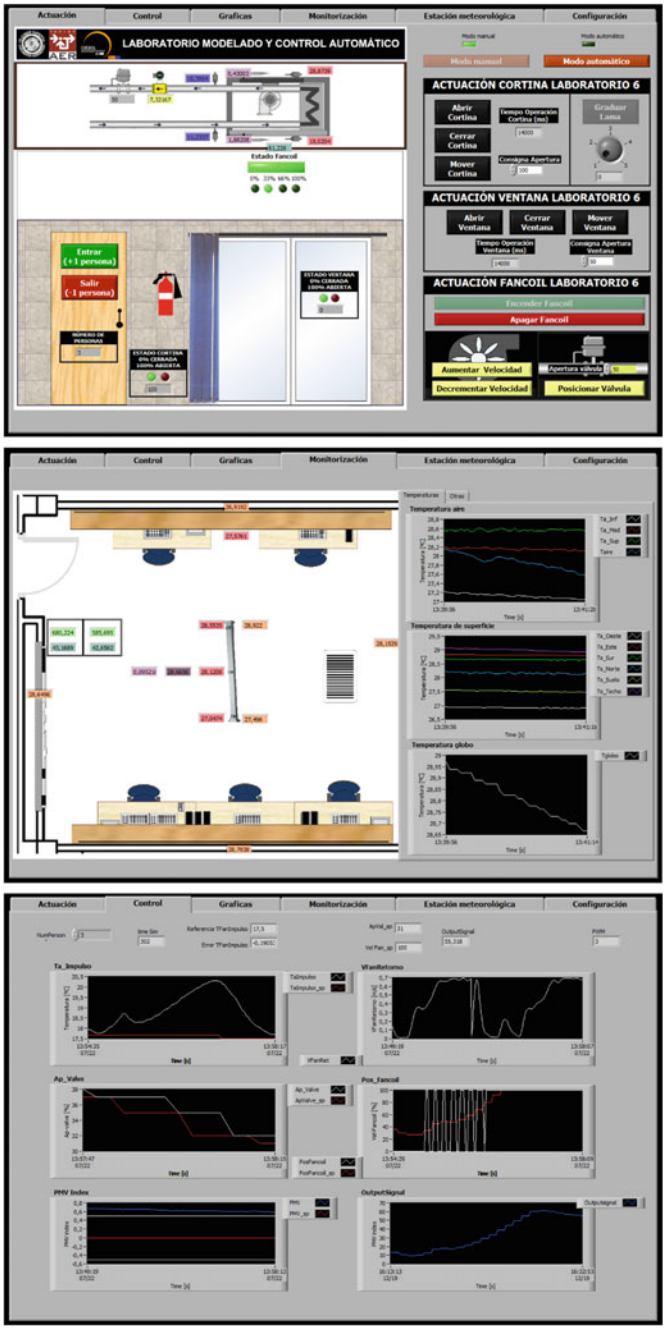

Fig. 2.20 Screens of the control module (labels in Spanish)

discontinuities in the data registers. In addition, it can also perform interpolation of these registers, if discontinuities are not too long. Finally, this module allows the extraction of several registers and, in this way, the user can generate data files of reduced size which contain only the registers associated to the sensors that are desirable to analyse.

- **Control module**
  This module was developed at a later stage in order to test the developed control strategies, see Fig. 2.20. More specifically, it was developed exclusively for a characteristic room of the building. Its main objective is to provide an intuitive interface which allows its users to test different control strategies and, at the same time, to supervise its behaviour at any time (it includes process diagrams, graphs, and real-time values). To do this, it incorporates a communication interface with MATLAB®, which is the selected software to implement the different control strategies.

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Comfort Control in Buildings
Castilla, M.d.M.; Álvarez, J.D.; Rodriguez, F. de A.;
Berenguel, M.
2014, XXIV, 237 p. 129 illus., 118 illus. in color.,
Hardcover
ISBN: 978-1-4471-6346-6