

Study on designing an automated system of efficient HVAC control for energy saving in industrial buildings

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Abstract. The article is focused on energy efficiency in industrial building automation and control activities. Within industrial buildings, heating and air conditioning systems (HVAC) must be well controlled. The main purpose of our work is to study and design an automated system of efficient HVAC control for energy saving in industrial buildings. Within our research, we have sought to obtain the optimal configuration of the automation network in the SIMATIC S7 programming environment, to realize the automation program, to define the graphical interface with the operator and to realize the configuration of the platform by the process simulation method. The relationship between building and the building's internal technical system consists of the HVAC system of the building, a system consisting of a series of interior installations, namely the building heating installation; the hot water production installation; the building's ventilation system; the building's cooling system. In order to achieve the indisputable level of quality, reliability and efficiency of HVAC equipment, equipments should be considered in their global environment. This means that in addition to the safe operation of equipments and the provision of efficient operating conditions, acoustic performance, energy savings, etc. will be considered. The increased energy efficiency occurs either when energy input is reduced for a given service level or services have been improved or increased for a given amount of energy input. Industrial buildings processes automation strategy is implemented through the Building Management System (BMS). The SCADA (Supervisory Control and Data Acquisition) network in industrial buildings provides an interconnection with the field elements at factory plant level. The SCADA command and control mode is based on the real-time data acquisition system in the process. These field elements, such as sensors, are monitoring in the SCADA network via a PC or a PLC (Programmable Logic Controller). The main results of our research are as following: automation of PLC & HMI processes; determining customer requirements; automation of PLC & HMI (Human Machine Interface) processes; determining customer requirements; realizing the system configuration for the automation process; realization of the process simulation platform architecture with SIMATIC S7-300 automatic programmable equipment. The most important consequence of the paper is the realization of a HVAC automation panel placed in a 4-level industrial hall.

1. Introduction

Understanding in-room airflow is crucial in designing HVAC installations for industrial buildings to achieve maximum thermal comfort and ambient quality. Sometimes an integral fan is added to reduce



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the internal resistance to airflow and thereby speed up air circulation [1]. Designing the HVAC system for a building and analyzing the energy consumption of the building would not be possible without a good understanding of the concepts and methods of heat transfer [2]. Nevertheless, the energy efficiency of the systems must always be taken into account. The desired result of an air distribution system in an industrial building room is to bring fresh air, to compensate need for heat or cold and to create a pleasant ambience in the area of occupation. The perception of occupants of the industrial plant is influenced by various factors that may occur in a room: air velocity, temperature, humidity, air turbulence, and the concentration of various pollutants, unevenness of the environment, various odors, etc. The way air circulates is directly related to the geometry of the room, the existence of people, the positioning of the windows and the discharge and extraction holes, and the nature of the ventilation / air conditioning systems. Measures related to air movement, temperature distribution and pollutants can successfully characterize the environments studied, but have the disadvantage of time and costs involved.

The Building Control System (BMS) provides control of about two-thirds of the energy consumption within industrial buildings. BMS is an integrated system enabling the management, control and partial automation of several building systems and functions [3]. The reduction of energy costs is achieved by controlling certain parameters of temperature, humidity, degree of lighting, etc., depending on the day, the outside temperature, the mode and the time of the activity in that industrial building. Compared to uncontrolled or unintegrated control systems, the BMS's control features provide significant savings. The BMS concept emerged from the need to manage an industrial building's environment or to control building parameters. The Parameter Concept in the BMS context must be perceived as the value of a certain measurement or condition description in an application (temperature, humidity, closed / open, active / inactive). This system is a great utility when we are managing the expenses of a large industrial building through the possibility to coordinate from one locate all the parameters of a building regardless of the distance to the command point and to accommodate their interdependence scenarios (parameters).

Also, implementing a BMS in an industrial building ensures the following:

- important energy savings: electrical, thermal (other primary energy sources);
- less power installed, so lower equipment costs;
- increasing the life of the equipment serving the building;
- achieving comfort parameters close to specific activities;
- elimination of dozens of regulators required for zone control of parameters required for decentralized local control.

BMS systems are generally implemented in large industrial buildings with complex installations and equipment due to the need to centralize information and system management for their functional and energy optimization. Centralized BMS can integrate all systems (industrial building installations): air conditioning and heat generation systems, lighting and electricity systems in general, access control and anti-burglary systems, fire and safety systems, etc.

The BMS system is provided with two dispatcher computers:

- One for special safety systems: access control, anti-burglary, fire surveillance;
- One for HVAC (Heating Ventilation Air Conditioning) and Electric systems.

2. The heat sources in a industrial building

In a building the heat sources are related (HVAC installations provided in the building design) or inherent (heat sources that add to their destination the heat - electrical and lighting appliances, human body, etc.). The heat sources of buildings represent a second set of sizes that participate in their thermal calculation, adding to the external variations of thermal conditions in which the building is. In order to determine the causality of thermal variations in the buildings, a balance of heat sources is needed [4]. It should be noted that this balance is not a passive one in the sense of determining the sources that participate and determining the behavior. We need to take into account the fact that our ultimate goal is the establishment of a thermal comfort for people working in that industrial building.

The HVAC system features and operating laws are developed to manipulate thermal balances in desired comfort zones.

2.1. The structure of a centralized BMS management system

A centralized BMS management system must have a modular structure that takes into account the installation and operating conditions of the existing managed equipment and allows for further network expansions (depending on the future development needs of the building), figure 1. Any BMS system architecture consists of three hierarchical levels, as described below, from the lower to the upper level, as follows:

Level 1. Data collection equipment and drive equipment (field equipment);

Level 2. Automation controllers equipped with communication interfaces - used for HVAC, Electricity, Plumbing, etc. (eg: ventilation plants, fireplaces, thermal power stations, electrical panels, etc.);

Level 3. Central management post of the system: dispatcher of the BMS system.

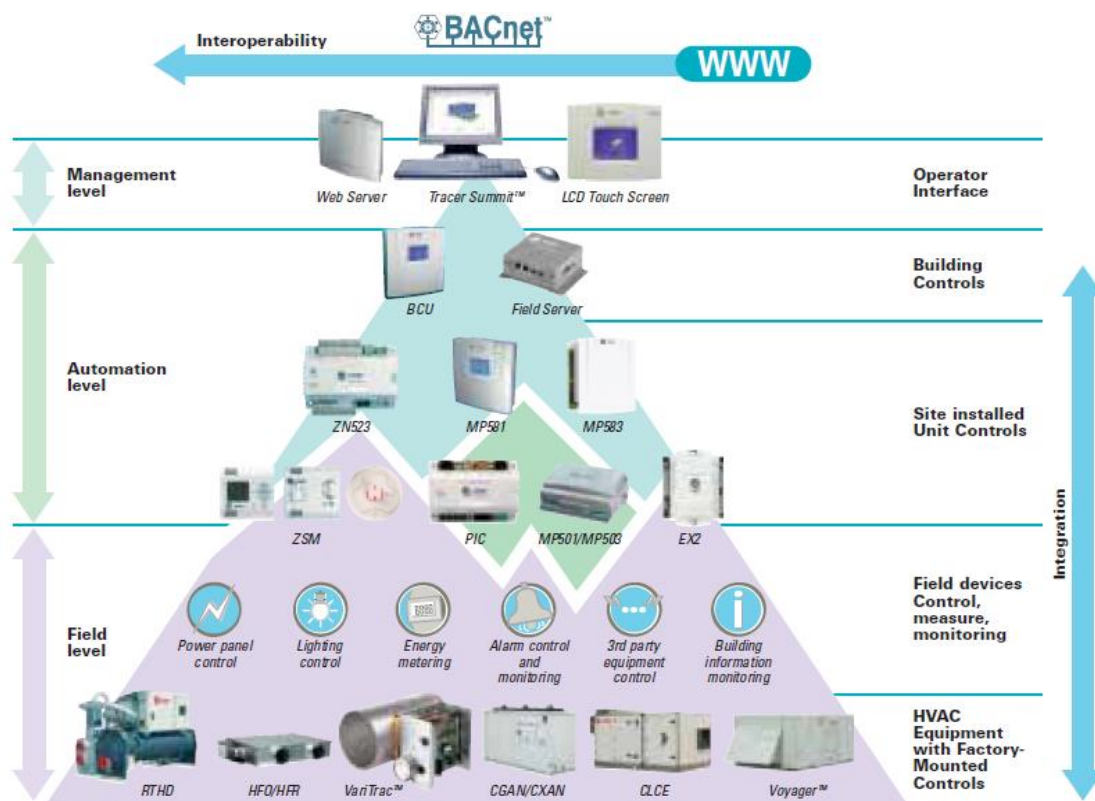


Figure 1. Hierarchical levels of a centralized BMS management system.

In the centralized driving system (BMS), each equipment or automated system will be able to operate independently in local control (equipment, plant) for which it was provided and connected to the communications network at the central dispatcher. For integration into a BMS system, local automation controllers must be provided with communication interfaces [5]. The use of specific protocols limits the possibilities of integration and involves substantial additional costs for subsequent developments / integration. The use of standardized communication protocols ensures the possibility of further integration for new equipment or systems installed in the next steps. The communication between the local controllers of the various systems (HVAC, SANITARY, HEALTH, ELECTRICAL, etc.) in the centralized management system will be made on several networks according to the communication protocols used (LON, MODBUS, BACnet, etc.). The network structure will be in line

with international ISO standards. Networks will be optimized so as to allow maximum transmission speeds in a network of any size and size.

- HVAC (Air Treatment Plant, Thermal Power Plant, Central Cooling Plant, Ventilation Convector, Ventilation);
- Plumbing (water supply, pumping groups, counters);
- Electrical (electrical panels, measuring stations);
- Other systems (lifts, generatorS, etc.).

2.2. Simatic STEP 7 software

Using the STEP 7 software, we could create a S7 program within a project (figure 2). The S7 programmable controller consists of a power supply, a CPU and input and output modules (I / O modules). Programmable Logic Controller (PLC) monitors and controls equipment (installation) with the S7 program. The I/O modules are accessed in the S7 program via addresses.

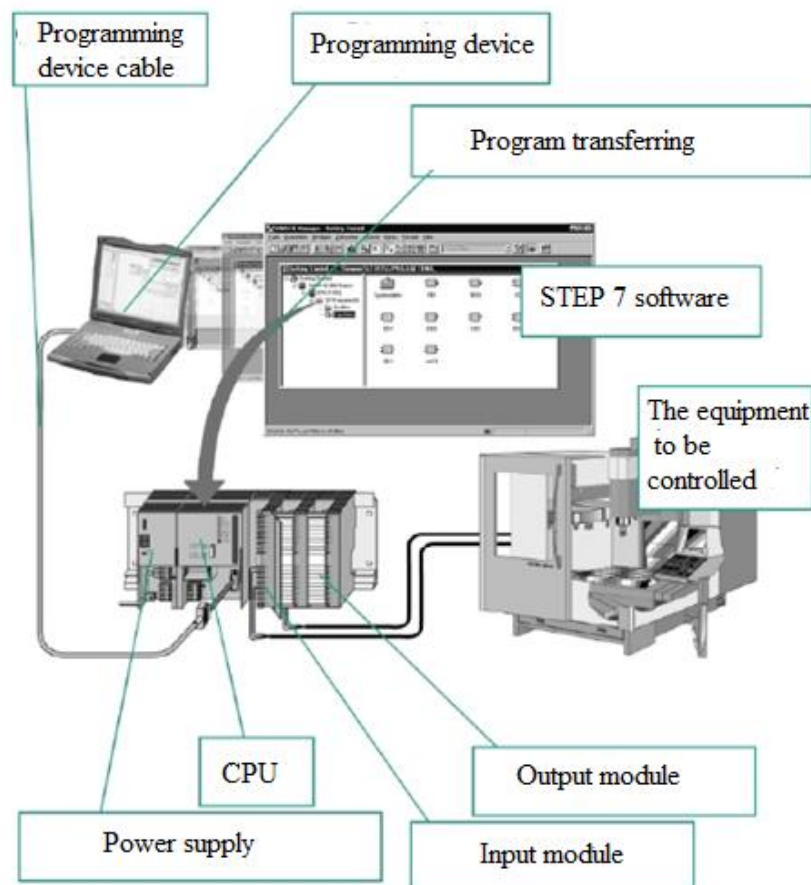


Figure 2. Overview of an automation project.

2.3. Basic procedure using STEP 7

Before we create a project, it's a good idea to implement a program in STEP 7 for a specific application in several ways- figure 3.

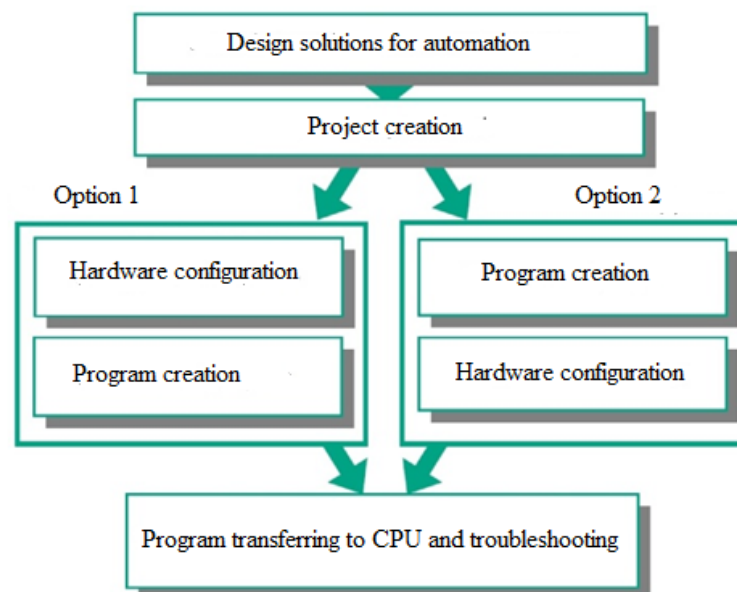


Figure 3. Creating a STEP 7 application.

If the application is more complex, with multiple inputs and outputs, it is recommended to initiate the hardware configuration. The advantage is that STEP 7 displays the possible addresses at Hardware Configuration Editor. If the second option is chosen, the user will have to choose each address based on the selected components and can not get help from the STEP 7 environment. Hardware configurations can define the addresses and change the parameters and properties of the modules. After these steps, the program is transferred to the CPU and the operation is tested.

2.4. The application for the introduction into the HVAC system of the industrial building of the possibility of controlling a heat source in the building by means of a switch.

To enter the Step 7 programming environment, we can choose one of the following:

- Access directly from the desktop via the icon on figure 4;
- Starting from Start and following the instructions given in figure 4.

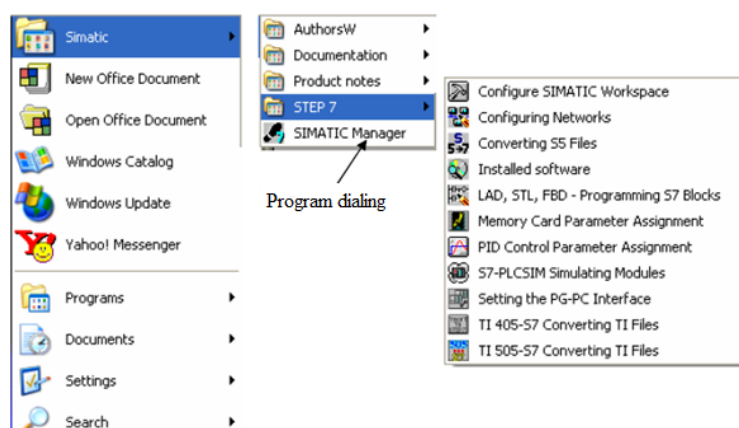


Figure 4. SIMATIC dialing modes.

In the last window in figure 4 we can see all the component modules. The important start modules are: LAD, STL, FBD - Programming S7 Blocks and S7-PLCSIM Simulating Modules. The first option allows writing of programs without going into the Simatic Manager environment and the second is the simulator that allows the testing of programs in the first phase without the need to use the programmable machine. Figure 5, 5a, 5b, 5c shows the 4 steps for opening a project. It can be seen in the 4 windows the choice of the central unit type (CPU 314 IFM) and the programming mode (LAD)



Figure 5. Step 1 for opening a project.

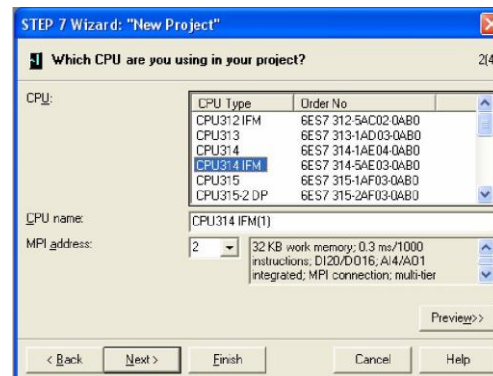


Figure 5a. Step 2 for opening a project.

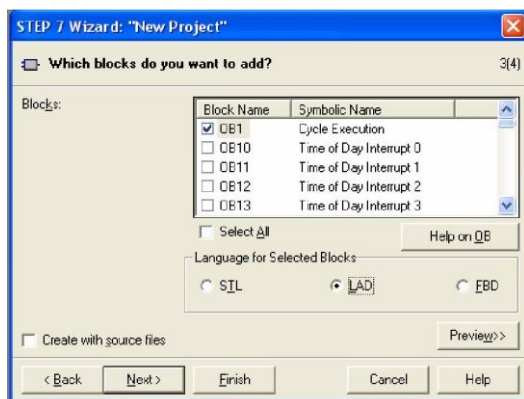


Figure 5b. Step 3 for opening a project.

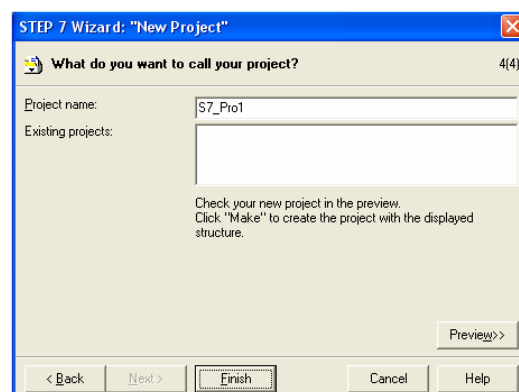


Figure 5c. Step 4 for opening a project.

Figure 6 presents project resources and organizational blocks.

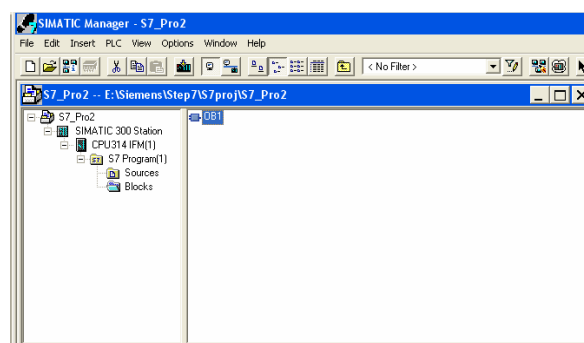


Figure 6. Organizational blocks (OB1 only).

For the example project, only the basic organizational block, which is cyclically called: OB1, was

chosen. By actually opening the project, we actually get the window for writing the application "Entering the HVAC system of the industrial building the possibility of controlling a heat source in the building by means of a switch- figure 7.

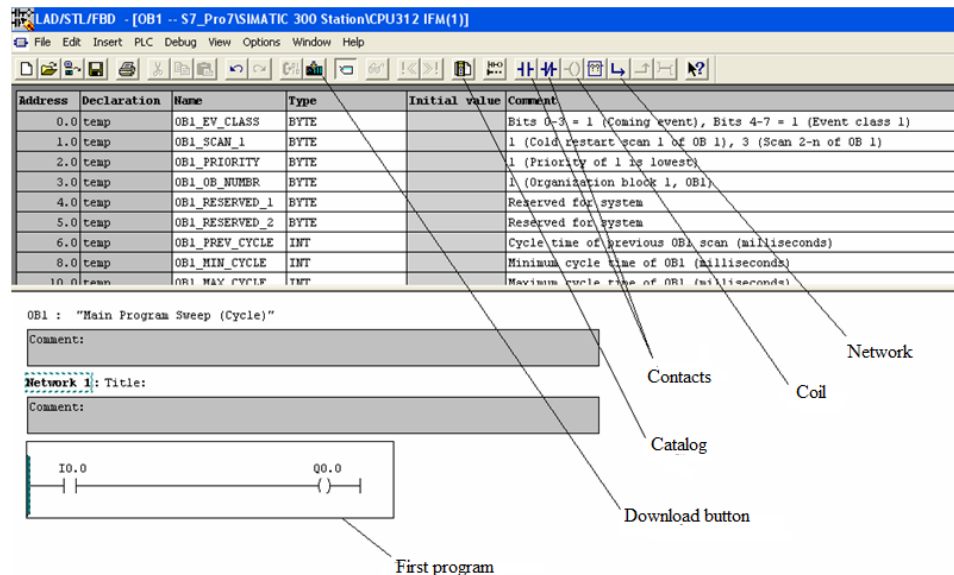


Figure 7. Control of a heat source in the building by means of a switch installed in the HVAC system of the industrial building.

In figure 7 you have the main elements that appear within a ladder diagram based program. Contacts and coils can be entered using the menu bar as well as new networks (program blocks). As variables we have I for input addresses, M for memory variable addresses and Q for output addresses. Program testing can be done using S7-PLCSIM Simulation –figure 8. By opening it and making a download that allows the program to be embedded as if we had a programmable as attachment, we can see if the program was designed correctly.

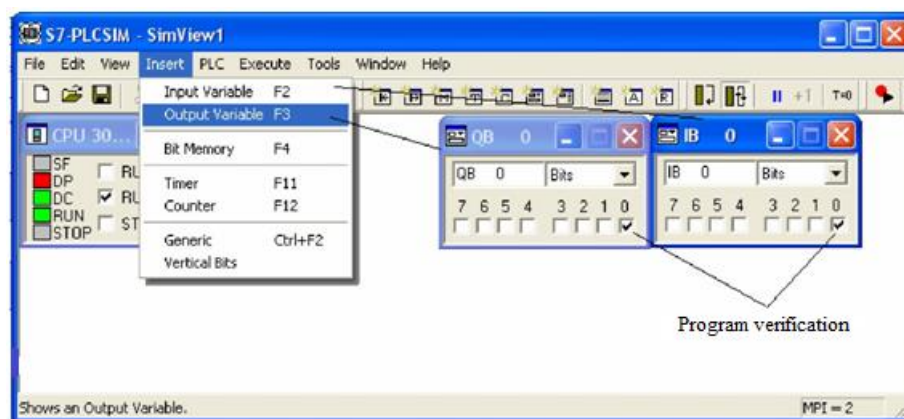


Figure 8. Testing the performed program using S7-PLCSIM Simulation.

In figure 8 we notice that the input I 0.0 check causes output Q 0.0 to be activated, which leads us to the correct solution of the application so that the program works according to what we wanted initially to supply the heat source when the switch was switched on.

3. SCADA - Supervisory Control And Data Acquisition

SCADA is mainly used for transmission and distribution networks in industrial buildings.

3.1. The components of the SCADA systems

SCADA systems are made up of different components connected to each other.

Measurement, actuation and measurement automation components: in the case of fluid transport and distribution networks, pressure, temperature and flow are measured; voltage, current and frequency are measured for electrical networks;

Measurement components: can be digital or analogue measurement instruments (connected to an analogue-to-digital conversion unit). The digital value of the measurement is taken over by the Remote Terminal Unit (RTU), which evaluates the measurement result, initiates commands and communicates the measurement results to the central processing system.

Drive and automation components: for fluid transport and / or distribution networks: control valves, taps or pumps; for electrical networks. These components are connected to the RTU or PLC which, based on commands arriving from the central processing system, performs operations.

3.2. Hardware components: computers, printers, monitors, intelligent process control modules, programmed logic control modules, storage units, etc. These components provide support for processing, storing, inputting, displaying or printing data; for safety reasons, it is common to use redundant elements to prevent data loss or interruption of operations.

3.3. Software Components

- Operating systems (real time or not), data acquisition systems, database management systems, simulation programs, communication programs, data archiving / restoration programs. These systems provide support for processing (operating systems, program running and development environments), providing means for tracking, viewing, and processing data. Based on some processing, certain components / modules can initiate different operations (controlling actuators and automation);
- Communication programs provide links between different elements of the SCADA system;
- Database management systems (there must be a real time database that records momentum values and supports real-time processing, and on the other hand these data will be recorded for further analysis in conventional databases).

3.4. The methods of data recording are as following:

- depending on the time characteristics of the records;
- continue - continuous monitoring of process parameters;
- selective - monitor values in a given period;
- acyclical - determined by events, eg recording current values in critical conditions where maximum values can be exceeded;
- depending on the structural characteristics of the records:
- process
- monitoring the entire process;
- subprocess oriented - with the selection of subprocesses being monitored.

3.5. Communication components

- LAN networks, network cables (coaxial cables, UTP, optical), network cards;
- Telephone lines, modems;

- Means of terrestrial radio communications, transmitting stations, transmission relays;
- Means of satellite communications, satellite broadcasting stations.

Communication components provide the data flow inside the system. In order to prevent the partial or total fall of the system, redundant communication means will be used.

3.6. Functional architecture

In order to provide decision support, SCADA systems must offer a wide variety of services as following: data acquisition service, communication service, remote commander service. The data collected by the measurement modules is transmitted to the local and central processing elements and the orders given by the operators or the procedures initiated by the central processing system or by the local decision modules are transmitted to the execution elements.

A data acquisition service is designed to verify data consistency, detect transmission errors, determine possible calculation errors, and so on. If one of the exceptional conditions has occurred, the alarm service is triggered. Alarm messages can be displayed on the screen, sorted and filtered in chronological order, by priority, by the current status of the alarm (active / inactive), the source that produced the message, or other options.

3.7. Operating Interface

In order to monitor and conduct the process, it is necessary to follow up on a synoptic panel the layout of the network, display the status information, initiate the possibility of commencing some orders, display the details of certain areas, etc.

3.8. Tracking and analyzing trends of variation of variables

Tracking trend variations of state variables is important, and can be used for diagnosis and predictive purposes. For this purpose, a history of events is recorded in a database, which, besides the status values, contains any alarms and orders given by the operators. Consumer analyzes are useful for detecting daily, weekly, monthly and annual consumption peaks; based on these data, parameters for predictive analytics can be set.

3.9. Security Service

Access checking in the system is done by the security service, which allows access based on passwords and access levels, defining ways to disconnect users.

3.10. Diagnostic service

The system must provide the ability to quickly detect network failures and locate them as accurately as possible. It must also be able to provide all the data regarding the possible elements involved in the repair of the fault.

3.11. Data archiving service

The development of a data archiving system is necessary for further analysis / processing, as well as the production of production reports. At the same time, the data must reflect the state of the network as accurately as possible, and the system can provide the most complete picture of the events states on the network.

3.12. Simulation service

The simulation service system allows analysis of "what happens if" scenarios. These may refer to the impact of developments, network expansions, crash situations, etc. By simulating the network it is also possible to interpolate the values at some points where measuring instruments are not fitted.

4. The characteristics of SCADA systems

Opening: The system's ability to undergo further expansion. This feature is achieved by using the open system concept (Open System). Opening must be present both in hardware, software (different operating systems and portable code), communications (international standards: PROFIBUS and OPC (OLE for Process Control), MPI, Industrial Ethernet, TCP / IP etc.) as well as in terms of data management (SQL Expression)..

Integration: Ensures interoperability with other systems, such as the enterprise information system, design system, consumption billing system, LAN / WAN workstations, distributed driving systems, manufacturing management systems, modeling systems processes, optimization systems, etc. The most common programming environment used in the system is the interface with the MMI / HMI - Man Machine Interface / Human Machine Interface operator.

Adaptability: ability to configure components according to concrete requirements, even if these requirements change over the life of the system; the ability to connect new equipment or programs to the existing system.

Tolerance to fault: it is ensured by redundancy in acquisition modules, communication, processing units, etc.

High availability: can be achieved through modular components and redundant elements, as well as the possibility of self-testing, isolation and bypassing of faulty modules.

5. HVAC Systems

For all utilities in the industrial building for which a BMS coupling is desired, automation systems with monitoring, adjustment, command and protection functions must be provided. All these systems are stand-alone entities and work independently whether they are coupled to BMS or not - figure 9.

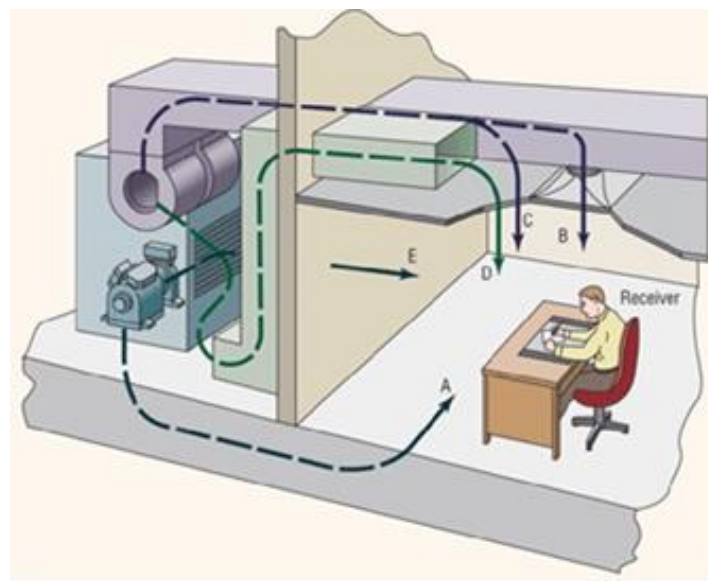


Figure 9. Industrial building HVAC System.

To increase efficiency, to ensure increased quality, all HVAC system manufacturers have to introduce to market state-of-the-art technology with better and more reliable systems. Industrial building HVAC System is based on a microprocessor system or multiple microprocessors controlled by a master processor that performs total system control. A Industrial building HVAC system is much more complex, it can have hundreds of indoor units and several outdoor units. Everything needs to be controlled from one place (table 1).

Table 1. Recommended control modes for HVAC systems.

Application	Control mode
Space temperature	P, PID (Process Identification Number)
Mixed air temperature	PI, Enhanced PID
Coil discharge temperature	PI, Enhanced PID
Chiller discharge temperature	PI, Enhanced PID
Air flow	PI (use wide proportional band & a fast reset rate), PID
Fan static pressure	PI, Enhanced PID
Humidity	P, possibly PI for tight control
Dewpoint temperature	P, possibly PI for tight control

All synoptics are to be elaborated on the basis of the Beneficiary's indications, specifying the need for synoptic information, technical control characteristic, monitoring for each separate component. It will determine the format and type of drives, the level of protection and the level of access to some or certain orders / parameters to be monitored. The alarms management will also be established, identifying the list of necessary ones with the appropriate priorities. The display parameters on the Operator Panel are placed the required information.

The command and control system - is structured on three levels:

1. The execution level: composed of the central PLC (CPU 315-2 PN / DP) and the LOGO automata from the control and command system attachments that will take the commands from the user interface to the control and command system associated with the devices concerned by contacts and relays.

2. The central user interface level: made up of the touch screen.

This is the brain of the control and command system. Both the touch screen and the PLC read the state of the systems, and on the basis of the user's commands, perform the command for each system. The touchscreen acts as master in the system.

Also, if the control (touch screen) is off, then each system can be controlled locally by means of the selectors in the control panels (Manual or Automatic).

3. The communication level: This level includes all the equipment and transmission means required for the interconnection of the other two levels. It is made up of cable sections connecting the remote points of the system. Communication is done on the KNX network with the help of modules designed to transmit data to the central station as well as to amplify the transmitted signal.

6. Touch screen

The Human Machine Interface (HMI) is Simatic HMI 377MP type. It is extremely reliable with the main purpose of providing a means of monitoring and control easy to use by maintenance personnel.

On the screen, the user can view the operation of the monitored systems as well as the buttons for controlling them. The control is accomplished by accessing 8 screens for each process.

7. Simulation Process Platform Architecture with Simatic S7 300 Automatic Programmable Equipment

The SIMATIC S7 300 programmable automation equipment is the class of mini-programmable automatic machines for small and medium-sized industrial applications and performances where the number of input / output signals does not exceed 8192. This family of programmable logic machines is suitable for automation functions of complex technological equipment or a technological line made up of several machines in a section, but of course also in other sub-branches of the industry, as in our case the data processing for an HVAC system. The SIMATIC S7 300 automated programmable family includes CPU Numerical Processing Units with varying degrees of complexity and performance

grouped into two classes: Centralized numerical processing units - Compact CPUs which, in addition to the communication ports, are integrated into the central unit module with digital and analogue signal acquisition channels and numerical and analogue command processing channels.

Centralized Numerical Processing Units - Standard Type CPUs containing only the processor and communication ports. In this type of central units, are attached SM, CP, IM, FM extension modules for acquisition and control as well as for special functions in accordance with the requirements of the technological process -figure 10.

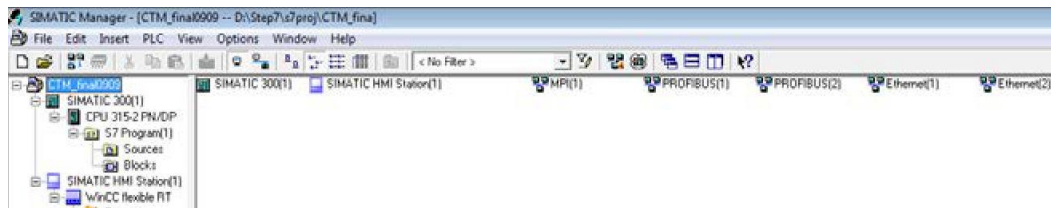


Figure 10. SIMATIC Manager - Equipment used at work.

With WINCC Flexible, the graphical processing of the interface is doing through the introduction of devices and the combination of visualization and control commands. Sending to a submenu is done by right-clicking on the button by selecting *Proprieties- Event- Press* and using the *Activate Screen* function, which gives the name of the screen and its address. *Screen activation* is shown in figure 11.

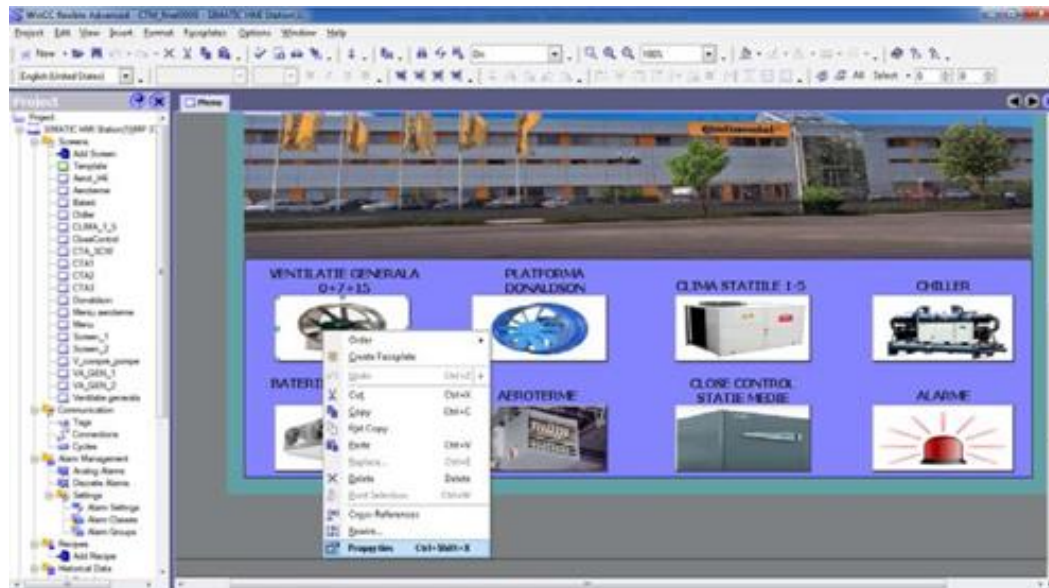


Figure 11. Touch screen main menu.and Screen activation

The procedure is generally valid for all submenus access buttons.

For the off / on commands a button was created using the right click to open *Properties - Events*. The line with the *WriteToLogo* function will be completed and the function defined in Step 7 of the OB block will automatically appear. Pass its network address using the ETS3 program by identifying the network device and selecting it from the *Logo S7-MainGroups*. Defining commands "*CTA Startup I*" Within value camp, the value 0 or 1 was turned on or off. In all cases for startup or shutdown, were

used entries I9 through I12 that represent network entries. By selecting the *Tag Menu* -figure 12, it is possible to enter the signals in the Data Bases where the data on the network is collected to view the states, temperatures and damage.

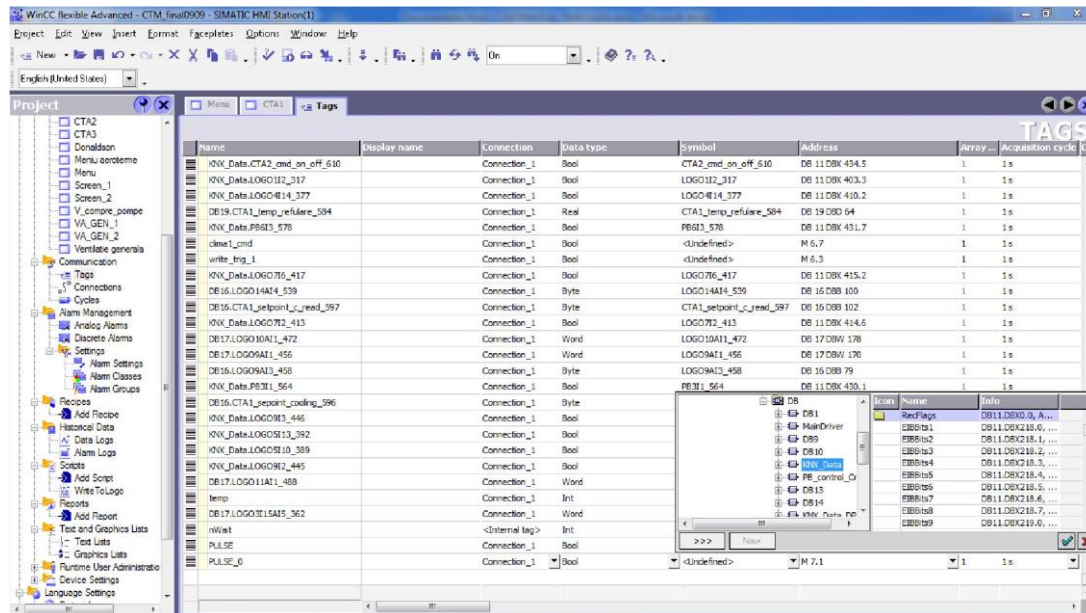


Figure 12. The Tag Menu.

For *on - off* status signaling, we right click on *Properties- Animation Visibility* and in the tag field we choose the digital input option (11-16) from where the input signal will be received:

- I1 - On - Off status
- I2 - Critical Damage
- I3 – Maintenance
- I4 - Operating Mode

For *On*, the *Visibility* field is ticked, to be active for *on*, and for *Off*, the *Hidden* field is ticked to be active for *Off*. We will do the same for the operating mode and for maintenance failure or critical failure. In the case of status signals, operating or fault status, the type of used data is Boolean. In the case of temperatures, the data type is Word (character raw), which will also be implemented in the TAGS menu so that it can be later selected in the properties of the field for temperature display. For temperature, select the temperature field by right-clicking *Properties - General- Process Tags*.

The type will be Output and the display format will be selected as desired by the user. As an analog signal, it will eventually appear with LOGOAI1. The connection between the automatic and the touchscreen is made by selecting the *Communication - Connections* menu and a window will appear to the right. The first connection is the link between PLC and MP 377, and the second connection is the interface between the touchscreen interface and the MP 377.

For connection 1, selecting automatic communication devices, will be inserted the data set in STEP 7 through the *Configure Network* menu.

The second connection is the connection between the touchscreen interface and the MP (Multi Panel) 377 and can be accessed from the already existing industrial network.

Device settings are made by selecting *Device Settings*. These options can be checked based on user preferences. At the end of the settings, a program compilation is done by selecting *Project-Compiler- Rebuild All* to update the new settings in STEP 7. To load the software with the new changes, select *Project-Transfer-Transfer*. After the software transfer, the transfer mode and its network address are selected. Then we click on *Transfer*.

8. The Soft Comfort Logo Program

Programming the LOGO controllers on your computer with the LOGO Soft Comfort program is much simpler and more comfortable than direct programming. In this case, all the elements in the catalog, as well as all elements of the automation scheme, chosen from this catalog and arranged according to the actual scheme, can be placed on the monitor. At the beginning, a new file must be created through the *File menu* and the *New* option, while selecting the desired programming language - FBD or LAD.

9. Conclusions

Taking into account the current performances in Romania, more than for other countries, energy efficiency is an important means for sustainable development and for accelerating the process of improving the competitiveness of the country's industry. By applying energy efficiency programs in different industrial sectors, the energy intensity per product unit will decrease, which will lead to a significant increase in the market competitiveness of the product concerned. In designing systems, numerical models allow for simulations and optimal solutions for HVAC systems in industrial buildings. The design of HVAC systems in industrial buildings is made from complete electrical parts and supports operative automation. With the help of the described system within our article, both substantial energy savings can be achieved through efficient energy management measures and by replacing classical consumers with some energy efficient, and substantially increased financial and ergonomic comfort.

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