Verification of smart building control algorithms

Tomas Sysala and Petr Neumann

***Abstract*—** Article deals with smart building supporting components control algorithm verification. Two simplified models of real devices are presented. The first one is a more complex five-floor lift model composed from two cages linked up for control. The second one is a family house simplified model where the centralized and decentralized control of smaller systems takes place. Heating, lighting, controlled access, security and air condition system are illustrating those smaller systems. The assumption for control algorithm verification is a programmable logical controller (PLC) controlling the whole system and exploiting all feasible communication variants.

***Keywords*—** lift model, real model, smart building.

I. Introduction

AUTOMATION and modern control methods are accompanying every step of ours nowadays. While the device control methods were absolutely prevailing in big industrial facilities applications and processes a couple of years ago, these methods are spreading to household, to our flats and to our family houses.

First efforts to design houses with a comprehensive related parameters control possibilities can be traced back to the fifties of the last century and the same effort has started in Japan in early sixties of the last century. That concept was not accepted in Japan at that time eventually unlike Europe, especially in Germany where the company Siemens was the leading innovator in developing relevant concept and devices for that application area.

For mastering and controlling any device, we need relevant wiring. Such wiring formerly served for lighting control. The current ground breaking information and communication technologies development offers an efficient possibility to control a wide range of devices like various appliances whose control would have been inconceivable about thirty or twenty years ago.

The lighting control, heating optimization, air condition and similar living environment parameters adaptation tasks have been already elaborating for decades. The TV and radio set control via WIFI or by a control unit via an IR signal, the voice control of all devices seen only in movies so far has to become reality nowadays.

II. Common versus Smart Wiring

As far as we solve a simple task, or the task is a small scope project, we are going to exploit a common wiring. Only when the project scope in relation to devices and peripherals extends, we start to consider if we can use the different way of communication or generally, the way of signal transmission between controlling unit and a controlled device. A “smart wiring” offers interesting qualities. Nevertheless, each way has its advantages and disadvantages.

The first project outcome attribute is the economical aspect that is very often the most important one. As already mentioned above, the price for common wiring related to small tasks is remarkably lower. The basic configuration cost of intelligent wiring is high because of expensive control unit what represents disadvantage in comparison to the common wiring. However, the cost difference decreases in relation to increasing number of connected devices what fact tends to deciding choice of intelligent wiring at certain project complexity level. That choice has number of advantages.

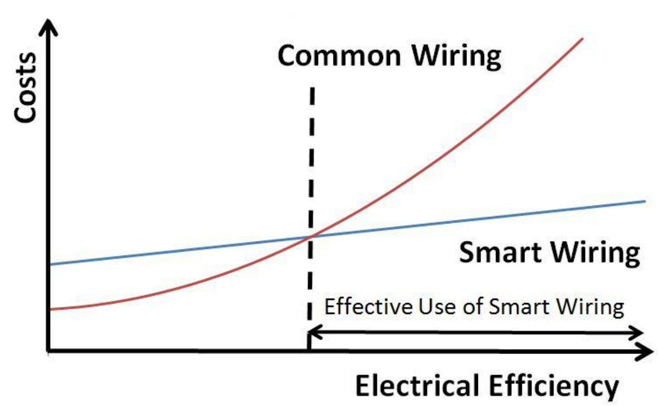

Fig. 1 Costs for common and smart wiring

A. *Automation and comfort*

- Simple one touch (or voice command) lighting control (gradual lighting run-up, predefined light scenes, etc.)
- One stimulus may initiate a lot of functions and activities. For instance, the arrival home initiates the temperature increase, light scene setting, slats draw and the like.
- Temperature can be adjusted according to predefined programs.

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Tomas Sysala is with Tomas Bata University in Zlin, Faculty of Applied Informatics, nam. T.G.Masaryka 5555, 760 01 Zlin, Czech Republic (corresponding author to provide phone: +420 57 603 5260; fax: +420 57 603 2716; e-mail: sysala@fai.utb.cz).

Petr Neumann is with Tomas Bata University in Zlin, Faculty of Applied Informatics, nam. T.G.Masaryka 5555, 760 01 Zlin, Czech Republic (e-mail: neumann@fai.utb.cz).

- The whole system can be controlled by desk top computer, tablet, or by other mobile device including a remote control via internet.

B. Security and Protection

- The realisation of protection system against an unauthorized intrusion is very simple.
- The failure and unexpected event occurrence messaging is very easy to be accomplished with SMS transfer.
- It is possible to simulate a standard house functions operation during resident absence period for the house does not give impression of a deserted place.

Appreciable aspect represents the energy economy concerning electricity and gas supply influenced by heating and other functions optimization.

III. Way of Control

The wiring type is closely related to the way of control.

A. Centralized

All inputs and outputs are star like conducted to the central unit. That unit is most frequently a programmable logic controller (PLC).

B. Hybrid

Some devices are connected to the control unit via bus system, some others via a star wiring topology like at the centralized way of control.

C. Decentralized

Each device has its own intelligence (it mostly incorporates microcontroller). All those devices are interconnected with bus. The whole system can or cannot comprise a control unit. Even if the system comprises a control unit, that is not for controlling but for command handing over, like for instance lighting command – “activate the scene arrival home”, or the heating command – “there is a holiday, heat as on Sunday”. The control unit puts out a command a it does not care for “how the device will perform that”. Device contains control algorithms.

IV. The Control Software Verifying

In case of project creation, we need to verify control algorithms for hardware control. The algorithm verifying is often not possible to verify with a real device because of controlled object destroying or damaging eventuality, alternatively involved persons (users) injury or putting them in danger.

Couple of models for functionality and safety of designed algorithms have been created at our faculty so far.

Further those models exploitation way of import represents their application PLC programming education and training. Students learn to program a real device which they may encounter in their successive professional life without any above mentioned danger.

V. Smart Family House Model

A Family house model (Fig. 2) consists of three main parts – a house building, a programmable controller and a control panel [1].

Fig. 2 Family house model

There are hallway, living room, two bedrooms, toilets and kitchen in the family house model. The house top view is shown in Fig.3.

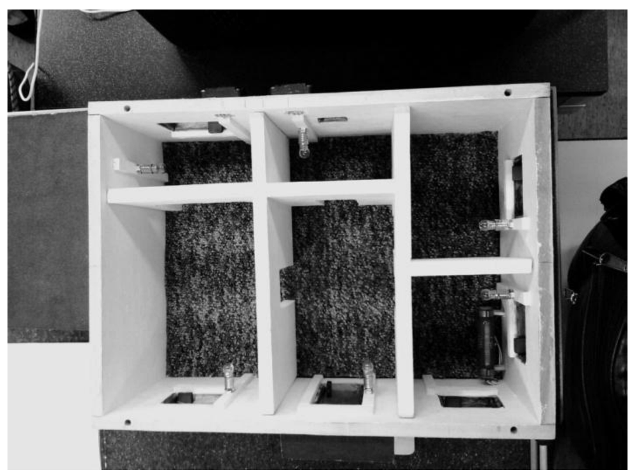

Fig. 3 Top view on the house model

The whole smart building functionality depends on control device stored program complexity. We can control lights in every room, fans in the toilet and in the kitchen. The garden entrance gate and also garage gate can be manipulated remotely. There is a small pool in the garden. It is possible to fill it with water or drain it according to user requirements.

Owing to window and door sensors, we can easily set up a security system.

The control panel contains a small keyboard with ten numerical keys (Fig. 4). We can pre-set arbitrary function for each key, but we mostly use all keys for security system control.

That part is massively exploited in educational process. Each student can program his own security system. The security option makes possible to use that model in educational process not only for students with “Automation and process control” specialization, but also for our faculty students with specialization aimed at “Security technologies and systems”.

23 binary inputs *(from the model to PLC)*	
	• light switches
	• ventilator switches
	• limit switches
	• open window detectors
	• open door detector
	• doorbell switch
	• contact sensor in front of door
2 analog inputs	
	▪ reference temperature
	▪ real temperature
31 binary outputs *(from PLC to the model)*	
	• lights in all rooms
	• alarm lights
	• ventilator
	• doorbell
	• heating
	• motor door opening
	• motor windows opening
	• LED indicators of all inputs and outputs on the control panel
1 analog output	
▪ signal to the potentiometer on the control panel	

Table 1 Active elements in family house model

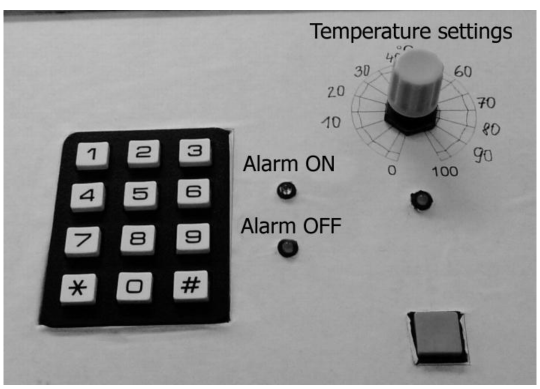

Fig. 4 Small keyboard for security control system

All controllable elements mentioned above, we activate mainly with push buttons and with switches. There are situations when we want to change the state of certain controllable device or we want to change a parameter inside the unit.

There are several possibilities how to change some parameters for a process control flow stored in PLC memory, or how to present data related to a technological process or PLC memory. Some of them are described hereafter.

HMI panel – Human Machine Interface panel is the easiest way to change parameters in the PLC. But this way has a disadvantage – we have to be close to the control PLC so that it is not a remote control situation.

The other way is to use common communication via RS232 or RS485. This way is used if PLC has exclusively these types of communication ports. We use this way in situations where we are using older PLCs. A PLC is connected to a personal computer or to another up-to-date PLC type. Through that device, we have access to all inputs and outputs of the first PLC.

Ethernet, Internet, Intranet access - current data PLC facilitates distributed industry nets establishment. All devices in this net have dedicated addresses so that we can send data to any PLC in that net. If our net is an industry net, we use a bus for communication. There could be used a Profi-Bus, S-Bus, ModBus or other protocol. We mostly use a TCP/IP protocol if we have a PLC connected to the Internet.

GSM Communication - if we do not have Intranet or Internet access, and we do not have any possibility to interconnect the controlled process with the control room via a cable, we can use a GSM module installed in the PLC. We can send or receive “Short Messages” (SMS) with that module. It is possible to transfer the parameters of the controlled system, like temperature or water level reading, and we can send SMS with control commands to the heating unit, water pump or other outputs in the PLC.

VI. SCADA Application for a Family House Control

The current trend aims at not only a functional system which controls individual components, but to create an intelligent system offering the above mentioned advantages plus a possibility to communicate with the system from anywhere via various devices like computers, tablets and mobile phones. We have realized one of such applications, and we have verified its functionality in pursuance of our project.

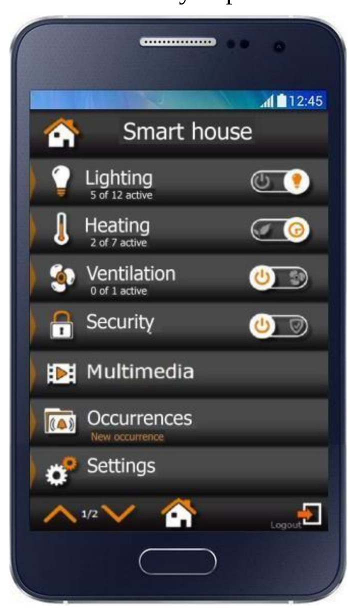

Fig. 5 The mobile phone application main menu

As was stated above, a PLC device realizes the main control unit. That PLC fulfils the web server function with an assigned IP address. A set of relevant data is present in a form of websites accessible via any web browser from any computer, tablet or mobile phone.

The application main menu incorporates the individual modules overview and inputs in particular house logical segments control. The main menu screen view illustrates Fig. 5. The information under each module indicates the number of the related submenu active items throughout the whole house. For instance, number of rooms being heated currently or number of lights currently lit [12].

It is not necessary to describe the whole application in details, nevertheless, the main functions description follows.

A. *Lighting*

The system copes with few light varieties according to the way of control. One variety represents lights to be simply switched on or switched off. The second one enables a continuous control via dimmers. The third variety enables the light colour control by composing RGB components in various ratios. The light sources can be controlled either manually, or according to the week schedule, or according to the PIR sensor state in corridors and outdoors.

B. *Heating*

For sake of operation simplicity, the Heating module uses only three temperature values defined by user. The *Minimal temperature* represents a required temperature value for situation when house residents are absent for a longer time period, like for instance a travel holiday. The *Temperature economy offset* is a certain temperature reduction. Such a reduced temperature can be required during night, or during any period of resident absence during work hours or school hours. *Comfort* temperature value is usually the highest one. It is a room temperature for residents staying home. The week heating schedule is based on these three temperatures. Providing we need a different temperature in a certain moment, we can enter a temporary positive correction valid for a limited period (for instance 3 hours). The programmed temperature according the week schedule is set back after that period expiry. The menu displays the actual temperatures scanned from indoor, outdoor and heating system sensors.

C. *Ventilation*

The extraction blowers in family houses are installed mainly in bathrooms, in toilets and in laundries. They serve for air exchange, and for humidity ventilation. The blower starts with the room light switch on.

Fig. 6 Lighting submenu

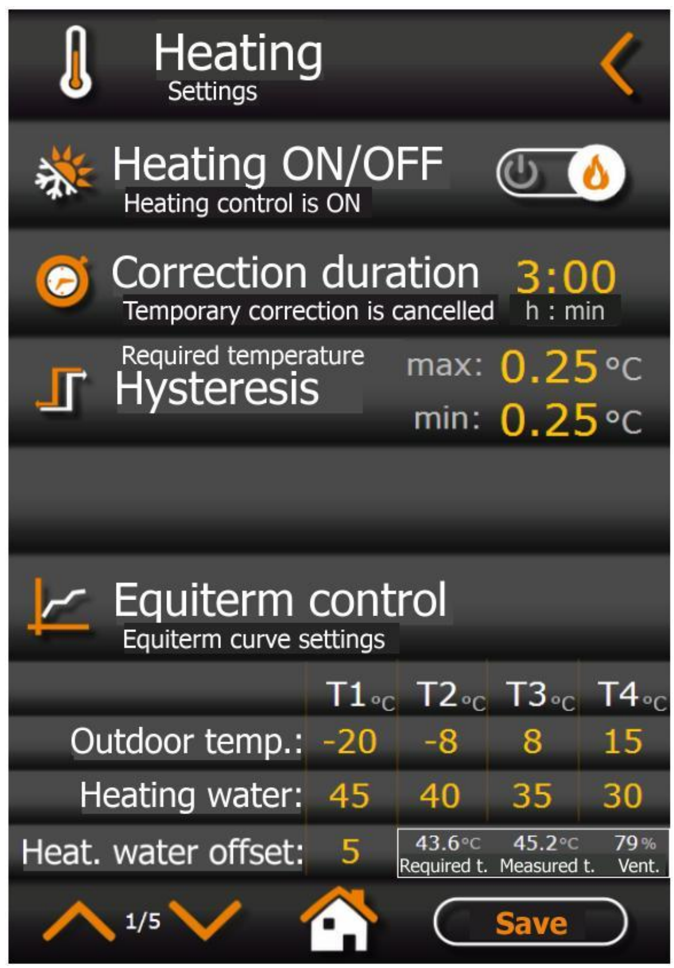

Fig. 7 Heating submenu

D. Security measures

The electronic security system interconnection with a smart house PLC offers the further extension of web application. The tile with open lock icon push starts the security system and it displays the period for leaving. Providing the security system is split in more subsystems, it is possible to control them simultaneously or individually. At releasing, we have to enter the same security code as we enter via electronic security system keyboard.

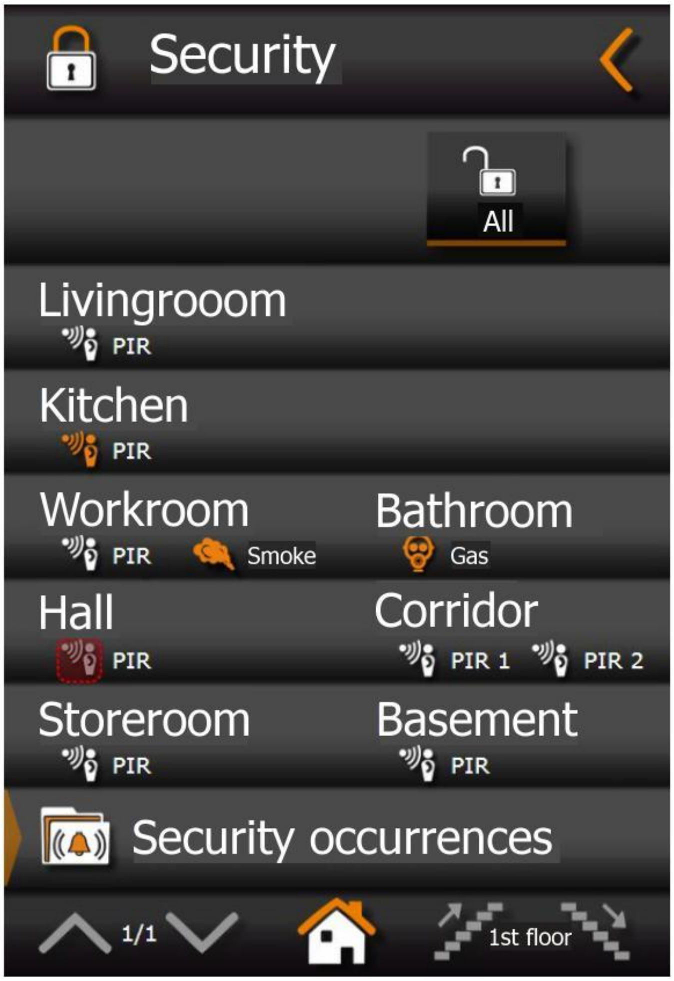

Fig. 8 Security submenu

E. Multimedia

That menu exploits the PLC module with an infrared (IR) output. Using this module, user can remotely control a TV set, radio, satellite TV and all other devices standardly equipped with an IR controller. It does not mean that the TV set is to be switched on from a globe distant place, but to turn down the TV set in another flor, for instance, or to start the interesting TV program recording in satellite, set-top-box or videorecorder.

A lift model is the second system developed for control algorithm verification.

VII. Lift Control

Majority of smart buildings has lift(s). There is mostly not only one lift but a lift group. It is not an easy task to originate a control program for the lift control.

Determinative factors for pinpointing a right lift control methods are primarily the following ones:

- Lift category (personal, freight lift, etc.)
- Building category (flat, administrative, hotel, etc.)
- Way of operation (self-service, lift operator assisted, etc.)

On the combinational basis of these determinative factors, there exists plenty of various control ways different operation and control automation levels.

A. Simple Control

The lift system can always accept and perform only one ride request. The moment a request is registered and being served, there is no opportunity for another user´s request to be served until the first request is fully attended to. There is a control button for cage call in at each lift stop. In case more buttons are pressed at the same time, the lower floor has priority [5].

B. Collective Control

The disadvantage of simple control is limitation to only one ride request to be served at the time. From the most effective transportation performance point of view, especially at higher lifting capacity elevators, is that way of operation very disadvantageous because of very low average cage occupancy. For the most effective lift utilization, the collective control is the right solution. It enables the registration of multiple requests from stops and cage at the same time. The requests are served with aim at the highest possible number of requests (transport of as many passengers as possible) to be served in the shortest possible time span.

C. Unidirectional Collective Control

Unidirectional collective control is used in economically advantageous cases like in buildings where the traffic from default stop (ground floor) to individual floors and from individual floors back to ground floor stop prevails. The mentioned way of transportation occurs in overwhelming cases in flat buildings where the traffic from individual upper floors further up is very rare. Unlike the Simplex control (bidirectional collective control), there is only one push control button with light indicator at all lift stops which is possible to stop with the not fully occupied cage passing the stop in down direction, or it is possible to call in the empty cage [6].

D. Bidirectional Collective Control

It is a most common lift collective control system design called SIMPLEX. The way of control is realized with two control buttons and a signal light at each lift stop. One control button is for the lift up, and the second one is for the lift down. By pressing one of those two buttons, the user sends to the control system the stop identification from where and in what direction is the transport requested.

There is possible to record an arbitrary number of ride requests in cage or at stops. Requests are served successively in order considering requests in direction of cage current moving first determined by a first recorded request. When there are no more requests in current moving direction, the serving of opposite direction requests is executed.

E. Group Control

Large buildings have a much higher need of vertical traffic so that single elevators are insufficient solution there. That is why they are equipped with groups of several elevators. In such a case, it is necessary to have elevator entrances as close as possible to each other, and the common control system is shared for all elevators, too. Only an appropriate group control system can ensure that the elevator group total transporting performance is higher than a mere sum of individual elevators performance [5].

VIII. Lift Model Description

We have designed and realized a two cages five floors elevator system model for control algorithm verification at our department (Fig. 5).

Fig. 9 Workplace with an elevator model [2]

The whole workplace consists of following parts:

- computer table
- computer for PLC programming or for elevator monitoring
- elevator model
- separated panel for cab control panel simulation
- PLC control Tecomat FOXTROT

Basic characteristic of the elevator model is as follows:

- 2 capsules
- 5 levels
- 2 electric motors for each capsule
- 10 small electric motors for each door
- 2 buttons and 2 LED indicators (cab annunciator) on each floor,
- 12 buttons and 12 LED indicators on personal control panel,
- 18 sensors indicating the cage position
- 10 closed door indicators.

IX. Control PLCs

Both models are controlled with PLC system SAIA – product of Saia Burgess Control Company.

A. PLC SAIA description

SAIA PLC looks like modular PLC and it is suitable for simpler tasks from the technological process control field, but it can be extended with up to eight different modules (binary inputs, binary outputs, analogue inputs, analogue outputs, communicating modules, etc.). [11]. We use PLCs Saia – model from the family group – PCS1 (model PCS1.C622), PCD2 (model PCD2.M140), PCD3 (model PCD3.M5540) in our laboratory. For smart building and for lift control the SAIA PCD2 is used.

Main properties and parameters of the SAIA PCD2 model are listed below:

- Central inputs/outputs - fit with any 8 I/O modules for up to 128 I/Os, additional 4/8 I/O module socket via expansion housing for up to 255 I/Os,
- User memory for programs, texts and data blocks - 1 MByte RAM in basic assembly,
- Flash-card - 1 MByte for backup the user program,
- Processing time - 2 μs bit processing, 10 μs word processing,
- Fast counters and interrupt inputs - 2, for interrupts or counting up to 1 kHz,
- Serial data port (PGU connector) - 1× RS 232 with RTS/CTS or RS 485 electrically connected,
- Serial data ports - 1× RS 232 (suitable for modem connection)/RS 422/RS 485 or 2× RS 232,
- Field bus connection - PROFIBUS FMS, PROFI BUS DP as master or slave, LONWORKS®,
- Ethernet-TCP/IP network connection - 2 × PROFIBUS DP as slave or 2 × LONWORKS®.

That was a basic properties and parameters set of the SAIA PCD2 model family. The PCD3 model family offers more possibilities. The model family PCS1 is simpler, but we have got a model, where the module MC35 is implemented. This module offers Short Messages (SMS) receiving and sending possibility.

The programming tool PG5 for SAIA®PCD programs creation is recommended. The whole system is organized in a file structure (containing several program blocks) what simplifies the shared use of program files between several SAIA®PCD controllers.

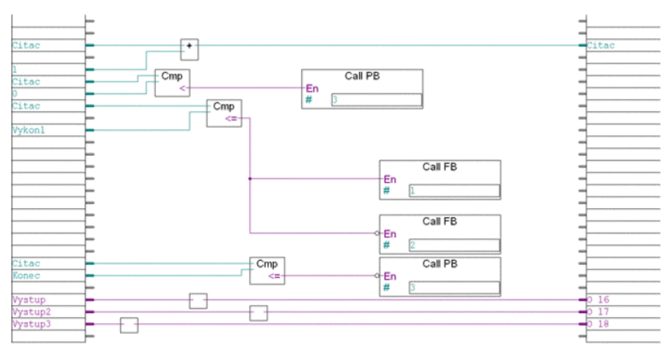

Fig. 10 Part of a program made in FUPLA environment

Each file and each part of a program can be created by means of various techniques:

- FUPLA (function block diagram),
- S-Edit (instruction list IL),
- GRAFTEC (sequential function chart).

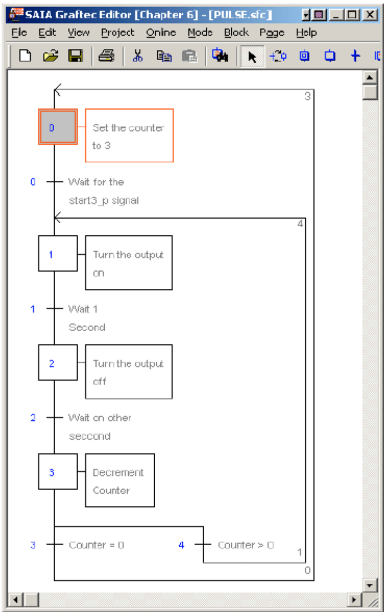

Fig. 11. Part of a program made in GRAFTEC environment

The Fupla editor is the simplest, fastest introduction to PCD controllers programming. The name "Fupla" means "FUnction PLAn". It is a graphical programming environment where the user draws programs with the aid of hundreds of functions. GRAFTEC environments serves better for sequential programming. The GRAFTEC program is created from transition conditions and steps mutually changing each other, and the program runs under defined conditions step-by-step. [11]

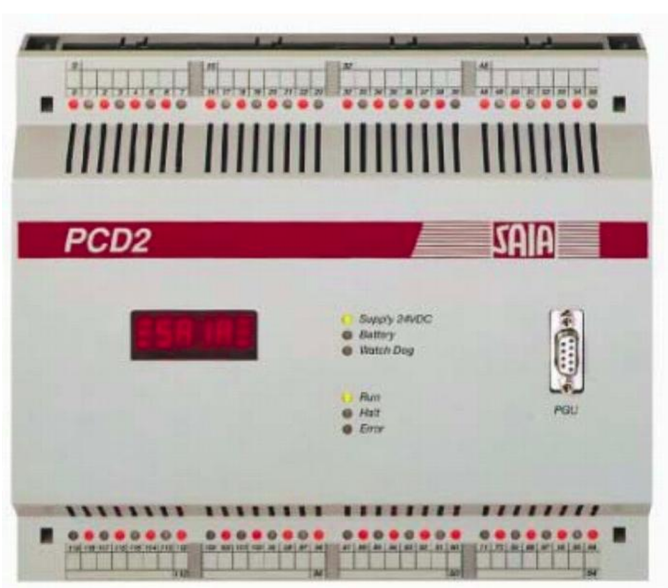

Fig. 12. PLC SAIA PCD2 [11]

The lift operation can be visualized in any SCADA/HMI system. The InTouch systems by American company Wonderware and ControlWeb system by Czech company Moravian Instruments are used in our application predominantly.

X. Conclusion

The main project goal was to design and create working equipment for the verification of smart building components control algorithms. By such a verification performed on a real installation model, it is possible to prevent damages and destruction of the controlled object, the real object closure because of tests and the last but not least reason for such approach is to prevent user injury at an incorrect functionality.

Two models for algorithms verification are representing the outcome of our project.

Students are also making use of those systems in course of their educational process and their preparation for future jobs and cases they may encounter in praxis.

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