DEMONSTRATOR

AE 26189

Building Management System controller

Microprocessor based digital direct controller for building management

STEC Control, Lda.

AE Abstract

BMS controller
Microprocessor digital controller for building management is more flexible

STEC Control, Lda., Portugal, was established in 1990 developing, producing, marketing and installing electronic equipment for Building Management Systems. The company has 3 employees with one involved in electronic design.

Building management systems (BMS) are aimed at all big buildings or households which need to have a simple and reliable way to control and monitor all aspects of its management. The future trend is to bring BMS to all building that are constructed. STEC has a 10% market share of the total Portuguese market, which has an annual value of 2,2 MEUR.

The company has only one type of product for which it has been using third party controllers from a British company with very limited features. Although these controllers present a good performance, cost is high and programmability very difficult for the common user. Software tools provided by the third party are very low-level and require a string expertise in these matters from the user side.

The new product is also based in a microprocessor device having all the features presented by the third party plus a communication network with distributed control. Through the use of this network and a PC software application, a Control Centre will be capable of monitoring most important activities in building management with a simple procedure.

For the successful conclusion of this project independent consultants were used. This was important due to the small number of people that work at STEC Control.

While cost advantage is achieved with a much more competitive controller, simplicity and flexibility is also added, withdrawing much of the usual engineering overhead during installation. The increment of these capabilities at STEC Control cost 40000 EUR and took 9 months. FUSE investment will be returned in a little over one year, with a ROI of 428%.

The experiment is of interest for companies that are entering into microelectronics and need to use a generic programmable logic controller with open architecture.

Keywords:

Building management system, domotics, microprocessor, temperature control, humidity control, lightening control, fieldbus, use of consultants

1. Company name and address

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2. Company Size

STEC Control is a small sized company with 3 employees with yearly overall revenue of 250 KEUR. The 3 employees are mainly dedicated to the development, fabrication, installation and set-up of building management systems. The base knowledge of the company at the start of the AE in microelectronics was in PCB development using discrete conventional analogue components. The introduction of a new technology in our products implied the commitment of all 3 employees to the AE. Their expertise and function is as follows:

- Mr. Damas Trindade – General Manager and
- Mr. Bruno Miguel – Software development
- Engº. Pedro Cunha – Hardware development

As the resources of a small company like STEC Control are limited for the execution of such large AE, we have also used external consultants to bring us the necessary complementary know-how, allowing us to take the maximum benefit of this AE. Consultants were need for PCB design, communications hardware and software development.

3. Company business description

Stec Control is a company specialised in the development of turnkey solutions for building management systems (BMS), comprising the following steps: specification of architecture and software, development of software applications, installation and operational set-up, and training for maintenance.

We represent in Portugal a system produced by a British company. It is directed at building management a several types and sizes. Our revenue comes delivering the total solution for the customer, including all the necessary steps as described above.

This proven expertise and business capability has allowed us to enter the industrial control field supplying our new industrial customers similar management but simpler and less demanding design solutions from the engineering point of view.

4. Company markets and competitive position at the start of the AE

Building management systems (BMS) are aimed at all big buildings or households which need to have a simple and reliable way to control and monitor all aspects of its management. The future trend is to bring BMS to all building that are constructed. This will start becoming possible as equipment prices come down and installation becomes more easy.

The building management systems (BMS) market is very specific. One cannot afford the possibility to supply equipment without reliable software applications. It is sometimes more important the quality of software application instead of the hardware used. Hence, it is of extreme importance the effectiveness of a company to provide both equipment and engineering expertise for the BMS field.

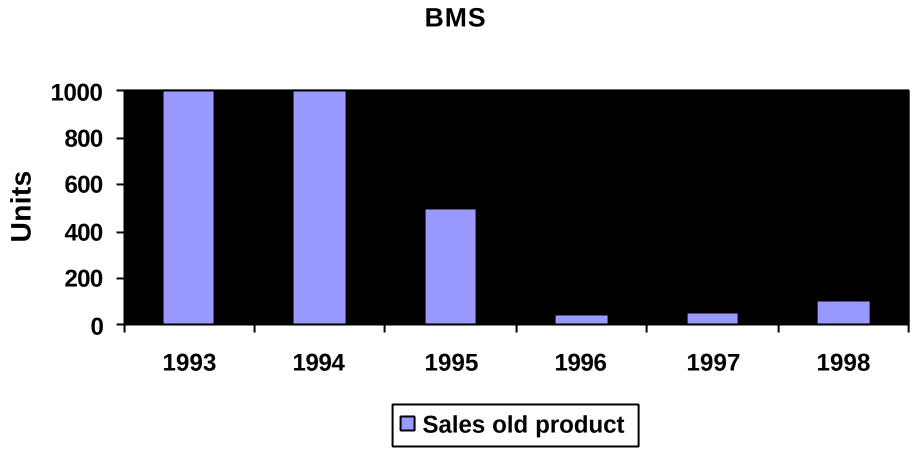
Stec Control was able to deliver both hardware and software until 1995/1996 using their own hardware equipment (the STC7000). However, due to its full analogue characteristics, this controller has rapidly lost competitiveness against fully digital devices introduced on the market by other quite known brands or companies. We have then decided to stop production of the STC7000 and to find a suitable replacement in order to maintain our business activity.

We start representing and distributing for Portugal the equipment from a British company. Many others were available but they were less flexible and reliable at this time. Although, this partnership was benefiting both sides, due to the facts that the British company did not have any business in Portugal and we had access to technological competitive equipment, it suffered from important disadvantages that have given rise to the execution of this application experiment.

The main problem was cost. This is particularly influenced by two factors: the exchange rate between Pounds and Escudos, which has increased in last couple of years, and the overhead of manufacturing costs, usually high in UK when compared to other countries. Still, cost is sometimes a secondary issue in the BMS market, where customers seek for reliable, flexible and effective applications that provide stable conditions of operation around the clock.

Within this framework, STEC Control has been able to build a reputation in the field of BMS solutions with a 10% market share. The total Portuguese market has an annual value of 2,2 MEUR, but this number is rapidly going up. Important competitors like Honeywell (USA), Landis & Gyr (CH), Staefa (CH), Stachwell (UK) and Cylon (USA) have also their own share of market. They make use of local distributors and installers, which do not have any proven solution of both hardware and software. Some have very good equipment with poor software applications, while others have medium rated or good equipment with very complex software tools development that require an high level of expertise in the field of BMS. This broad picture is giving hard times for both engineering and installers staff.

Our goal was to double our market share in Portugal (which is where we have been able to sell our BMS solutions up to now) and to regain the market of equipment. By recovering the ability to develop low-cost hardware equipment integrated with a very versatile and flexible software tool, using our established expertise in the BMS business, we will be able to provide full-featured and easy-like BMS solutions. The placement of the DDC against its competitors is such that will allow using simple programming for non-expert in BMS and sophisticated engineering solutions common to the manufacturers that use complex software tools dedicated to BMS.



The table shows the sales figure for the last 6 years of STEC Control activity in the building management market. The first three years represent sales figures of our own analogue controller. In 1995 the analogue controller was obsolete and a replacement was needed for it to maintain our activity. As we said before we seek for alternatives in the foreign market in which we have found several manufacturers not all having the desired functionality. Still we have decided for a British company to supply the controllers for our activity in building management. Therefore, sales figure after 1996 only represent the controllers sold that were supplied by this British company.

The British controller used in the past years has an average sales price (depending on the configuration installed) of PTE 420.000$00 (2095 EUR). The margin given is 15% of total sales, which is related to the fact that STEC Control only distributes these controllers. Although the margin for the new product will be lower (in absolute value) as well the price (near PTE 9000$00 – 45 EUR), the new DDC provide innovative features that differentiate the product from other competitors and thus making the market to recognise its added value.

5. Product to be improved and its industrial sector

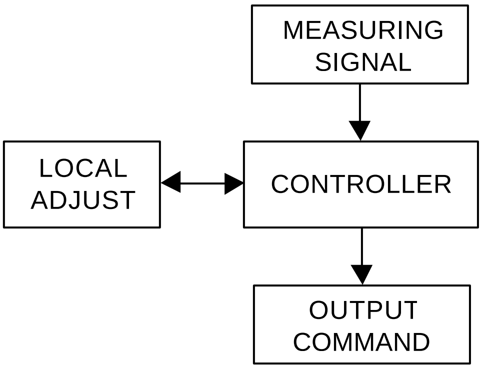
Until mid 1995, STEC Control had been able to supply simple hardware systems for building management control using a local controller, the STC 7000 combined a PLC device. The STC 7000 controller was used for measurement of temperature, humidity and pressure that, is mainly based in analogue components. The control action consists simply, in measuring sensors (temperature, humidity and pressure) and actuating voltage or current delivered to the controlled equipment, correcting power output until the sensors read a pre-defined value.

The analogue controller was obsolete and a replacement was needed for it to maintain our activity of supplying complete solutions in the BMS market. We have sought for alternatives in the foreign market in which we have found several manufacturers not all having the desired functionality. A family of more competitive controllers from a British company have been chosen for our activity. These controllers (IQ241 from TREND) are in fact more efficient with better performance, but have a high cost. Their aimed at general BMS for large buildings, where the main features are power, speed and adaptability. They are also very reliable.
These are the controllers that we have been using for last years up to the work developed in this application experiment.

This family of controllers have the following main features:

- 32-bit microcontroller (68332 from Motorola)
- 12 digital inputs
- 8 Universal inputs
- 12 Universal I/O
- 8 Analogue outputs

Next figure shows the block diagram of the British product:



Along with this hardware the manufacturer supplies software for development of applications. This software tool is responsible for the programming of each controller in the installation. The programming is based in low-level programming and requires from the developer a high level of expertise to install the system.

Although updated in technology, these controllers are not flexible and simple enough for a generalised usage of such devices in home automation that also requires low-cost components.

This equipment had many limitations that needed technical improvements, such as:

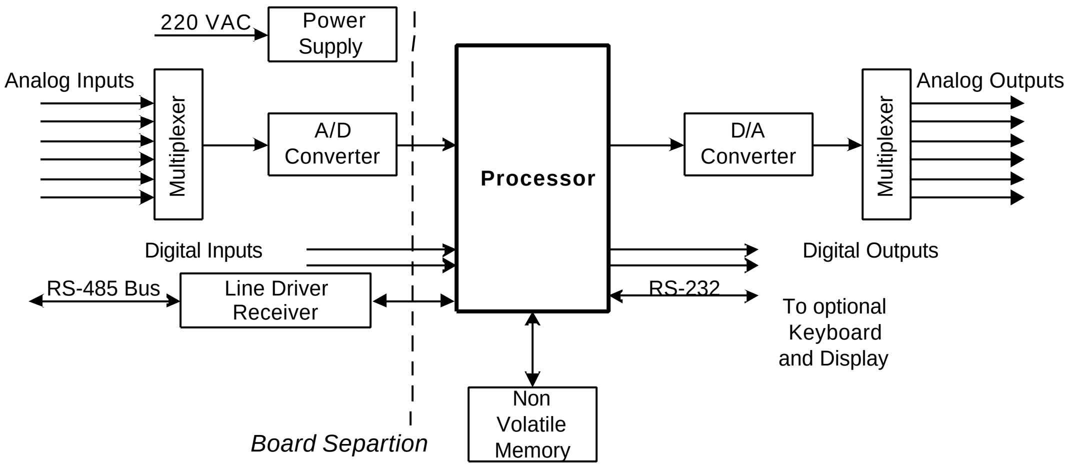
- Must be physically connected to both the sensors and the controlled equipment (as there are no communications involved), making installation difficult;
- The set point values must be fixed or if they need to be changed they must have an operator acting on a potentiometer;
- No complex algorithms may be implemented as they are very hard to perform with analogue electronics;
- Precision components must be used;
- Complex production trimming and periodical calibration are necessary;
- Large size (325 x 355 x 90 mm);
- Unfriendly user interface;
- Low accuracy (8 bits).

6. Description of the technical improvements

The new controller developed under this project is a DDC, which is characterised to have all the analogue inputs converted to digital and submitted to a full digital process as well as all the outputs are obtained by analogue conversion from digital results. Next figure shows the block diagram of the new DDC.

The controller has 8 universal analogue inputs configurable by software as active or passive inputs, from which 3 can be configurable as digital inputs. Also an analogue input for sensors has been included that could be seen also as a digital input. Finally, 4 fully digital inputs have been defined.

Regarding outputs the controller has 8 analogue outputs ranging from 0 to 10 V with drive current of 20mA each. These outputs could emulate digital functions being necessary that the digital level be programmed for each case.



Power supply is through mains. A backup system for power failure was not considered since actuators stop working when power fails.

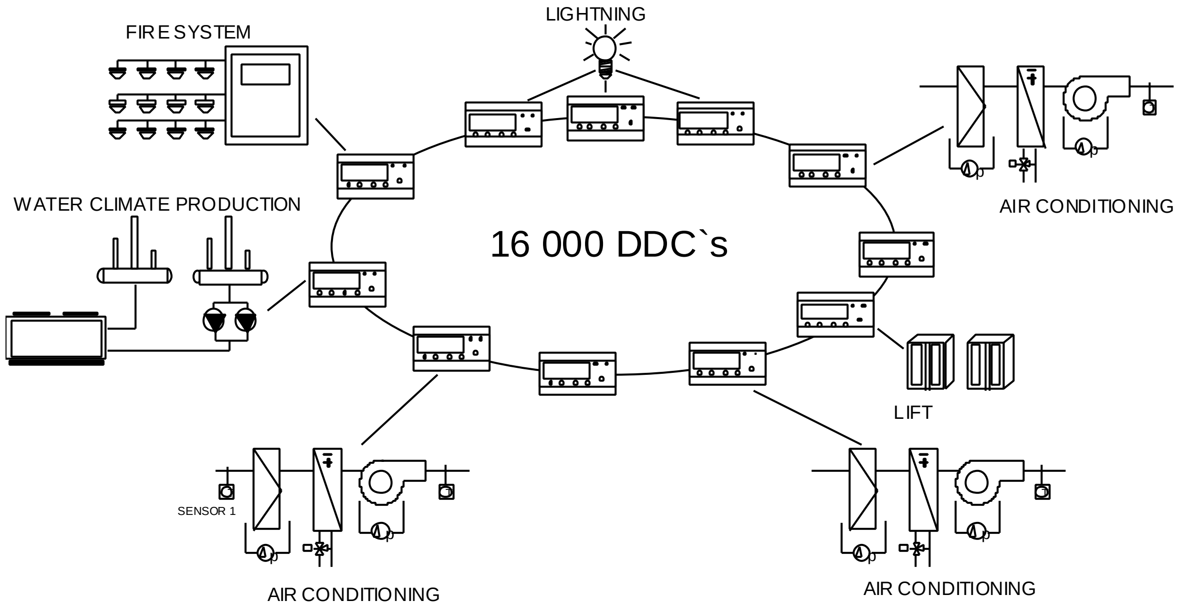
The main blocks in the above diagram are:

- A 16-bit RISC processor (PIC17C756)
- A non-volatile 2 to 4 Mbyte memory
- A real-time clock
- A high speed UART with RS-485 interface
- A second UART for local configuration using RS-232
- A 16 channel 10-bit A/D converter
- A 8 channel 10-bit D/A converter
- 8 current sources for passive sensors
- 8 20mA output drivers
- A graphical LCD display
- A keyboard
- An integrated power supply

This DDC has been designed with a communication system to enable the possibility to configure each controller remotely and also to monitor its functionality. On the contrary to other DDC based systems, the architecture is not of master/slave type, instead is of master/master. The network of DDC's (shown ahead) allows to dispose a maximum of 16000 controllers making the monitoring possible by means of a PC. The address of each DDC will be attributed during installation.

Controllers are dispose in a ring and they can communicate with each other. They can exchange between them a communication frame with 32 parameters. With this configuration DDC's can be programmed locally by RS-232 input or by the network through the use of a software tool developed for this case.

This architecture allows verifying the integrity in the communication ring and to maintain a failure detection system, being the DDC's autonomous to communicate among them even if one or more fails to do it. This way each DDC can have control of its communications avoiding the use of a master like in old configurations. The role of a PC is only to monitor activities in the network or to program configurations.



To maintain communications fast, a special purpose code has been developed to allow transmission rates of 1Mb/s. Also, distance between each DDC has been analysed since normal RS-485 bus only allow 1,5 Km with 32 addresses. We have designed our own Rx/Tx bus that allows 1 Km between each controller, which is more than enough for BMS systems. The communication protocol used can not be disclosed for confidentiality reasons.

From the functional point of view the introduction of this new open architecture allows to improve the use of BMS system either at user end or at engineering end. Especially at the engineering side designing can be arduous. We have developed a software tool that provides these two levels of expertise: supervision and engineering.

While in engineering mode the designer of BMS systems can use a predefined library that allows configuring each DDC with programmable logic. Here, we have logical blocks (Boolean blocks, timers, counters and relays), analogue blocks (ADCs, Minimum, Maximum, Average, Enthalpy, Gate, and Loops), and Inputs/Outputs (Switch, Pulser, Knobs, Drives, and Inputs). The DDC hardware has the necessary firmware to support these functions.

The improvements and benefits can provide enormous advantages from the user side:

- Electrical measures can be taken with any physical unit and with any range of values
- Design of configuration can be made graphically with the use of a schematic editing tool for conversion to a programming file that can be sent remotely
- Logical functions allow the definition of logical, mathematical, Setpoint, and manual command operators
- Registration of events (history file)
- Definition of an alarm file that can be edited either in virtual or real mode.

- Easiness to program calendars (definition of 3 holiday periods and of hourly, daily and weekly starts)

The technical improvements can be summarised as follows:

- Size – 3 times smaller;
- LCD graphical display (instead of digit only);
- Universal sensor input;
- Improved accuracy (4 times);

7. Choices and rationale for the selected technologies, tools and methodologies

The DDC is expected to be an innovation for the building control installers. The engineering effort will be reduce for each new installation. The flexibility and programming capability was required to meet specifications. In addition, specifications would require the possibility to upgrade the system and to include new features.

A microcontroller solution can provide both the flexibility of the OTP (One-Time Programming) options that allow the firmware to have a continuous upgrade in every new installation and the easy to learn RISC language that allows our company to quickly deliver each upgrade assisted by our field staff. Also, for production reasons the OTP microcontroller solution has shown to be very competitive as it allows us to have a larger diversity of models that differ only in the firmware and may so be produced, tested and stocked in a single lot reducing the production and inventory costs. These are also the reasons that show the main advantages over MASK production version of the microcontroller (the second option): the diversity of models to be produced does not allow supporting the costs of several MASK version of microcontroller. An ASIC solution was not chosen, because the investment for this is large and missed the required flexibility.

Several tools were used in the electronic controller development. These tools were available from the microcontroller suppliers at a very low cost and comprised a programmer interface, a simulator and an in-circuit emulator (to edit, compile, link, download and debug the microcontroller software).

The stocked products are to be loaded with the final firmware just before they are being delivered to each client without the need for complex marketing forecasts once the same stock may follow any distinct model order. Other technical and commercial reasons as the small, size, reduced number of extra components, reduced power consumption, code protection and low cost have also contributed to our decision.

During project execution more options and decisions had to be made in order to maintain the final cost under the established target. These are mainly related with technological issues:

1. **Analogue output configuration**
   Low cost and accuracy of the analogue channels were required at the specification. First we have considered using one DAC per analogue output, which would be costly and restricted by the available space in PCB. The option was to take advantage on the microprocessor and instead to use 8 Sample & Hold channels with a multiplexer.

2. **Firmware protection**
   One of the main objectives in this project was to ensure code protection. Initially, our choice was over the PIC17C756, which has a memory size with 16K RISC instructions of 16-bit, each. During project execution this was judge not to be enough and so, it was necessary to optimise program memory. Two strategies were considered. First, to include all the

operative menus in an external memory avoiding the use of program memory with characters and graphics. Secondly, some routines necessary to control the display and the analogue outputs were written directly in assembler to optimise space.

3. **Memory**
   Due to the high level of configuration that the DDC controller exhibits, it was necessary to develop a memory strategy. The amount of information that can reside in the controller can compromise the use of an E2PROM since the larger model available in market has only 256Kbit. In fact, the parameterisation of logical functions and the labelling of variables up to 20 characters each can generate more than 256Kbit. The only solution was to use a Flash memory that can range from 2 to 8Mbit.

4. **Date and time synchronisation**
   It was included in the DDC a real-time clock and a battery to maintain its functioning independent of any power supply. However, when a system is installed clocks should be synchronised. This was possible considering that one unit assumes to be a master and the others are slaves. Then, when communications are established all slaves adjust to the same time of the master. If communications fail, clock stays working autonomously until communications return.

5. **Communications**
   Communications between controllers would require long distances for which there were no ICs available. Using RS-485 drivers would limit the network to 32 devices with a driving current of 20 mA that would also be very sensitive to noise. The solution taken to overcome these problems was to develop an RS-485-like driver with higher performance and immune to noise. With this architecture for the network, as explained in section 6, distances over 1km between controllers are possible and much more reliable. We have also consider other options to provide connection between controllers like using the CAN bus for which state-of-the-art components are available from many manufacturers. A less complex and less expensive solution was preferred.
   A future development has also conditioned the choice for the network, which is the growing interest of higher bit rates over fiber optics connections. A simpler network like the one we have with a photodiode would be capable to provide 10Mbits/s over 12km distances.

In the past we had the capability to assembly conventional components by hand. The use of SMT assembly was a necessity for us to ensure that size requirements would match. Subcontracting a specialised service will undoubtedly be more cost effective.

A final word on services must be included here. We have found some difficulties in manufacturing the PCBs for prototypes. Alternative solutions must always be considered to avoid delays. Many foreign companies can provide this service with higher quality and on time. As we did during this project we will use this services for future developments.

8. Expertise and experience in microelectronics of the company and the staff allocated to the project

Since the start of Stec Control in 1990 we have been dedicated to the development, fabrication, installation and set-up of building management systems. Two kinds of expertise have been important to maintain our business: the ability to develop and to fabricate BMS controllers based in analogue components mounted in a conventional way (through hole) and the engineering expertise to provide BMS design and installation with foreign equipment.

Basically, our knowledge in electronics was concentrated in the capability to design PCB's with conventional components using software tools like TANGO, and to specify and design electrical schematics with analogue devices.

The tenths of building management systems already projected and installed are the baseline of our extensive knowledge in the BMS field. However, at the start of the application experiment, we had insufficient knowledge to develop digital hardware and software.

For this reason we had proposed technical training in three subjects: specification, design and CAD. With specification and design training we expected to gain knowledge in all steps involved in the development of microprocessor based systems namely, hardware architecture, software (firmware) specification and development, and testing. With the CAD design we intended to improve our knowledge of PCB design stepping up into the use of SMT components and best practices with corresponding software tools.

Another important lack of knowledge was in the management of technical projects. When we proposed the application experiment, we had to receive help from the TTN to organise and plan the tasks of this project. Still, we felt that we need to improve the decision making process joining the technical knowledge with a much better view of management tasks. Since we are a small company, the goal of this training was to introduce more effective practices that would contribute to improve the overall organisation and the global management of the company in future projects or correlated activities.

9. Workplan and rationale

The original workplan has been closely followed, although minor changes and delays had occurred. We will now explain its most significant stages, the rationale behind it and how the original plan has been adapted to overpass the delays.

The original workplan was according to the gantt chart in next page. In there we can identify five major tasks:

Management

Management has been entirely conducted by Stec Control. This task had a duration of 9 months including delays. The goal of this task was to provide the company with the ability to manage technological projects on time and budget.

Meetings with subcontractor and TTN were adjourned under this task. The participation of the TTN in these management meetings helped us to understand the basic principles in technical management. We had the chance to discuss the technological options, and changes to the work plan. Refinement and corrections of work plan have been implemented with the accordance of all participants.

A management task is important for two reasons. First, to have the commitment of all participants in the work to be done making this a place for discussion. And second, to be informed of all the necessary reports and documents to be delivered as we have never participated in such projects and didn't know how to proceed.

- **Training**

Training was constituted by 4 activities: management, specification, CAD and design training. Training was executed by the subcontractor on a one-to-one basis. Training was then, putted into practice during the development tasks with the advice of the subcontractor as a hands-on training.

Management training had the objective to provide us with the basic principles of technical management. Training had the presence of 2 participants. Subjects presented were about the workflow involved in this project and its reporting tasks, including the analysis of potential problems over the execution. This was the preparation to conduct the management task.

Specification training was required for us to understand the options available in the family of PIC microcontrollers as well as their capabilities. We had specified electronics in the past, which required hardware specification, but microcontroller software was a new field of possibilities that made this training necessary.

The same reason assisted execution of CAD training. We have experience in the design of PCB using conventional through-hole components. However, the transition for SMT components required us to improve our knowledge and capabilities in this field. Furthermore, we would have to deal with SMT assembly services making knowledge on this subject essential. The CAD designer has attended the training action that took place at the TTN.

As we said before much of the training was performed using the methodology of hands-on training. This was in fact, the best way to create the necessary expertise while executing the development of the controller. We recognise the privileged situation we had, since subcontractor accepted to assist our work with a comprehensive collaboration.

- **Specification**

Specification was divided in two tasks: Functional specification of DDC and Technical specification of DDC. In the first phase that had a five-day duration, Stec control specified the requirements for the controller (number of inputs/outputs, functionality, programming capabilities and so on). This has been evaluated and discussed for further detailing during the next phase.

The second phase discussed the architecture of the controller. Selection of components and its adaptability to specifications was the major issue. The mechanical design of case to accommodate the electronics was also considered. A particular attention was given in order to make integration of case and electronics perfect.

For this phase, competitors have been analysed and their equivalent product compared with our specification. This task has been underestimated in duration and only our extensive knowledge of BMS systems as well as the subcontractor knowledge in microcontrollers made possible to be on time.

- **Design**

The design of the DDC controller was the real development. A prototype of the DDC was to be developed and assembled for testing purpose. So, the first step after component definition was the design of electrical schematic and PCB according to the case geometry. This was a hard task since dimensions of case made it almost impossible. PCB was then sent to the manufacturer for prototype production. Two iterations of PCB design were necessary to fit the components into the foreseen case to be used when in production.

The task prototype production has been shifted from the evaluation workpackage. This reflects our decision to provide the real prototype for software development.

The second phase of this task involved the development of firmware code, which had 3 months duration. However, as many problems happened with the PCB production, the start of this task has been delayed 2 months. To optimise the development time, blocks of logical functions have been emulated in a PC with software from Microchip. Further integration and simulation of such blocks would require the prototype to test it in-circuit. The PC emulation has shown to be inaccurate with many conflicts.

The uses of a consultant was of particular interest us due to the very small team our company has (only 3 people). Only this way was it possible to take forward this project in an efficient manner. Otherwise our company would have needed much more human resources.

- **Evaluation**

  Testing has been executed either in a stand-alone form, with the software loaded in the prototype simulating the inputs and reading the ouputs (through means of the RS-232 port), or with 10 prototypes connected in network to simulate communications and testing the RS-485 connection between controllers. In this case a PC programmed the 10 DDC's and generated the communications.

  Compliance with EMC rules will be tested later when DDC goes into production. Field testing was not possible to execute due to the lack of a building place to do it.

A comparison between the planned effort and the actual effort is made in next table, which clearly shows where delays had occurred.

Proposed in Keuro

STEC CONTROL	Man / Day	STEC	Man / Day	INESC	Man / Day	ID 7
WP1-Management	25	3,325	5	1,600	5	1,175
Travels		1,000				
WP2-Training	20	2,660	10	3,200	10	2,350
WP3-Specification	12	1,600			13	3,055
Durable Equipment		0,800				
WP4-Design	17	2,660			50	11,750
WP5-Evaluation	25	3,325				
Travels						
Services		1,500				
Durable Equipment						
SUBTOTAL	**99**	**16,870**	**15**	**4,800**	**78**	**18,330**
TOTAL						**40,000**

Real in Keuro

STEC CONTROL	Man / Day	STEC	Man / Day	INESC	Man / Day	ID 7
WP1-Management	33	4,451	2,5	0,900	5	1,175
Travels		1,088				
WP2-Training	27	3,561	5	1,500	10	2,350
WP3-Specification	16	2,142			13	3,055
Durable Equipment		0,680				
WP4-Design	23	3,568			40	9,308
WP5-Evaluation	33	4,451				
Travels						
Services		2,254				
Durable Equipment						
SUBTOTAL	**132**	**22,193**	**7,5**	**2,400**	**68**	**15,888**
TOTAL						**40,481**

10. Subcontractor information

Stec Control found endless difficulties to arrange a suitable subcontractor for the proposed development. We contacted in the market several companies for them to propose integrated solutions that could provide technology transfer.

Four companies have replied to our inquiry in which we required good skills for microcontroller design (either in hardware and software), extensive knowledge of the proposed microcontroller, training experience, and the ability to understand the ideas behind this project.

We have selected **ID7** for a number of very positive reasons among the other competitors. Firstly, because they have maintained the baseline for this project with a very professional attitude. They have also shown a very large experience in the development of solutions for Robotics, Industrial control and Radio telemetry, which have revealed the ability to understand the application of electronics into different subjects.

They are very experienced in the development of PIC microcontrollers. This was in fact, a decisive factor for our subcontractor choice since it matched the technology choice. This experience was based on a significant number of real developments and in the training capacity of the company, which allowed them to propose the desired integrated solution of training and development. In addition, ID7 has been trained by Microchip USA and performs regular training actions in Portugal.

As the project was executed other important factors brought up the importance in the choice of subcontractor. The capability to communicate and understand the ideas behind this project shown that ID7 was remarkably experienced in specification. They were able to understand for the first time the role of the user in BMS solutions as we did when we learned from them the most important microelectronics subjects for this project.

Only ID7 had the availability to help us in performing feasibility studies and thus to estimate the final cost for the development and product. This was considered crucial for us since we had now an indicative value for the cost of product when in industrial production.

In the matter of industrial production, the relationship of ID7 with several contract assembly companies has ensured that production could also be easily conducted. For such situation, ID7 would provide after the project, a complete product dossier that would give us the possibility to choose the assembly subcontractor as we wish. Moreover, we would be responsible for the final stage in production, the programming of controller in-house, for which we will buy the necessary equipment. We will then, have the necessary protection against piracy or non-authorised copies of the controller.

Although ID7 had shown the capability to support the development of microcontrollers, there were other tasks where other kind of expertise was necessary. It was the case of PCB design, communications hardware and software development. To cover this broad range of expertise only a large company could provide the necessary service at very expensive cost and possibly with no benefits for STEC Control. It is usual these days to hire external consultants at fixed costs to develop a specific task. The main advantage of this strategy is that cost can be reduced and the consultant (if the product is successful) can benefit from industrialisation since it will be necessary his support for future corrections and upgrades of the hardware and software.

11. Barriers perceived by the company in the first use of the AE technology

As we said before, we at Stec Control are highly experienced in the BMS field. Our knowledge has grown over the past 10 years with a large number of projects and installations realised that provide us with the necessary cultural background. So, we had the chance to perceive and evaluate the complete requirements and functionality for the present upgrade though we had encountered some barriers that were mainly concentrated in knowledge and in technology.

Once the decision of using microcontrollers for this development was taken, we discovered a set of requirements (knowledge barriers), which we could not answer without the help of an expert:

- The choice of a microcontroller based on criteria's of quality, upgrade, cost, availability of internal peripherals, programming capabilities, and software protection.
- The analysis of cost and feasibility based on our technology choice.
- The development of a work plan for such project.

To enter the microelectronics world was never feared by the company. We were, since the beginning, convinced in taking this step. However, the major issue here was with whom. Therefore, from the technology point of view we have perceived the following barriers:

- How to select and manage the subcontractor for microcontroller development
- How to specify and design microcontroller based systems.
- How to select and manage SMT subcontractors when in production
- How to conduct a project with such technology integrated with different kinds of expertise (electronics, mechanics and software).

It is important to mention that we had, in the past, some experience in dealing with PCB subcontractors and with assemblers of conventional components, which helped significantly in the perception of the referred barriers. Still, it is important for others to include these as barriers if they had never dealt with such technologies or subcontractors.

Another major barrier for STEC Control was time. The FUSE funding was the necessary bootstrap to speed this AE, as we were able to hire the external consultants that in turn helped us to achieve results. We expect that our new product will be sell in the international market. Again without FUSE funds we could not improve time-to-market or to maintain independence, which were essential to add more power during negotiations with major international companies willing to commercialise our products.

12. Steps taken to overcome the barriers and arrive at an improved product

Considering that Portugal does not have a tradition in microelectronics, the search for a microcontroller subcontractor was assumed to be critical for the success of this project. We have searched for experts in this area either by contacting directly or by indication of consultants and local distributors.

Selection was long and arduous. The contact with four potential subcontractors and thus, four different proposals has given us some insight of different microprocessor technologies providing the means for comparison. From the reasoning in previous sections we have decided for ID7. They have propose to use Microchip microcontrollers that could meet our requirements of cost, availability of peripherals, powerful programming instruction set, and software protection. They also provided help in the analysis of cost and feasibility, and they have developed a plan with a time schedule for this project.

The TTN has also played for us an important role as an independent institution that had refined the cost and feasibility analysis and confirmed the technology choice.

Due to the high level of experience of subcontractor, management was easy. However, the commitment of a small subcontractor like ID7, especially when involved in many other activities, may compromise the time schedule. The TTN was again important to independently stress the subcontractor to be on time in its tasks.
Delivery times of regular services have affected the normal course of this project, namely the PCB production. Local companies tend to establish a long supply time for the production of prototype series. We overcome this problem by contracting foreign companies specialised in the production of prototypes. This was possible with the help of both the TTN and ID7.

The mechanical design of the product was another factor of delay since PCB design was provided in an iterative fashion until its final conclusion. It is important that both mechanical designer and hardware responsible are aware of the technology limits in order to avoid physical restrictions that could compromise the design of PCB.

Finally, the uncertainty factor is always present in microelectronics developments in spite of all market studies we could provide. FUSE has, thus, assumed an important role by providing the financial means to validate these studies guaranteeing the success of this product.

13. Knowledge and experience acquired

The most important gain in our capabilities was the introduction of new management capabilities. In a fast changing world like the microelectronics, to be able to decide on the use of new technologies is an important asset and should be done carefully. Thus, we can now:

1. Evaluate new projects and its feasibility using microcontrollers from the technical and economical point view
   - This capability will make us able to analyse in future developments its feasibility defining an appropriate work plan. This project has increased our cultural and technological background giving us the necessary confidence to decide if a product is economically viable and if its development using microcontrollers can make it competitive.
   - We know to estimate the necessary time for a project using microprocessor
   - We can also set up the necessary logistics to start a new project, meaning we know what is necessary in terms of equipment for a microcontroller development and production.

2. Choose a suitable microcontroller for our developments
   - PIC microcontrollers are suitable for a significant number of applications. Nevertheless, the procurement we did just before the start of this project gave us the comparison means to understand about each microcontroller features and advantages. We can now choose the best microcontroller for our present application, which is not necessarily a PIC although we have acquired a development tools for it.

3. Select the appropriate subcontractor for the microcontroller development
   - The initial phase just before the start of this project was quite profitable. It helped to explore alternative solutions while we perceived that subcontractors could have a different level of understanding, which is proportional to their wisdom and expertise in the business. Contacting and discussing the solution with several subcontractors taught us the way for selection.

- Specification is an important barrier for this choice since most of the time subcontractors don't have the knowledge about the area for which they should provide a solution. Thus, when subcontracting capacity to specify should be analysed. We can now do for ourselves the complete specification of microcontroller based systems.
- The relationship with external consultants was deemed too important for the correct completion of complementary tasks and is regarded as beneficial for the company since they are competent professionals that may join the company as business develops.

4. Subcontract SMT assemblers
   - While in the past we had experienced subcontracting conventional components knowing about their own requirements for production, we found different requirements in SMT assemblers that should be considered during project. Thus, we have increased our knowledge in this area and we are able to design PCB with SMT components.

Regarding development capabilities we are able to specify a product using microcontrollers, to design the electrical schematics, to develop code for the microcontroller, and to test the code using in-circuit emulation (ICE) techniques.

14. Lessons learned

The learning process executed during this project provided a huge amount of information. This information is of great value for an area (BMS) that requires that we stay competitive.

The most important lesson withdrawn from this experience is our capacity to define the necessary working team and thus how to manage electronic projects. When we start to develop the idea for a project, the development team should contain specialist in different areas that are required for the project. This way we can have a better evaluation from objectives and barriers minimising costs and delays.

The use of Microchip microcontrollers was a particular choice of our project. We learned that offer is high and so, possibilities making comparison of features an essential issue in the choice of microcontroller. One can have more address space while other can have more peripherals. It may take many years of experience in doing such developments, to be able to decide. So, contacting several subcontractors to explore different solutions is the best way to avoid trial and error method in the technology choice or in the microcontroller choice reducing the time of development.

We learned that project size and its characterisation will provide the basis for choice, and definitely, PIC microcontrollers may not be the best choice as it was in this case.

In this line of thought a supplier like Microchip may require shorter development time as they are also constantly changing to be competitive in their market. We had experienced during the project changes in the data-sheet specification regarding the packaging of our chosen component. This can produce nasty effects in the delivery time, as project has to be redesigned. This should be a consideration for the evaluation phase, since we are sure that many other supplier do not change as much as Microchip.

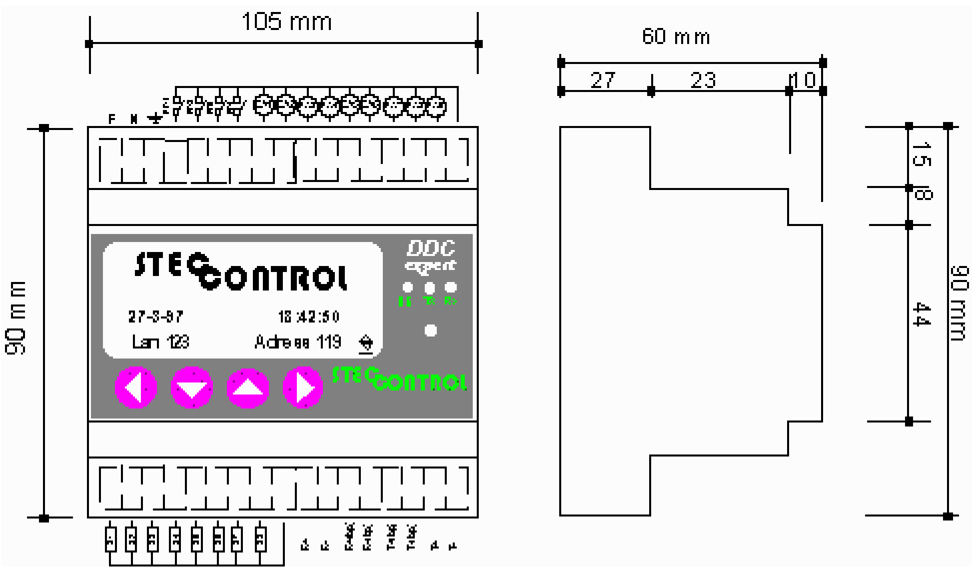
15. Resulting product, its industrialisation and internal replication

The resulting product is a prototype of the DDC. All the required functionality is working correctly and has been tested with a fully working system, including the exchange of messages over a real network under real working conditions.

Industrialisation has been considered. The previous work during prototyping with the SMT assembler allowed us to analysed costs involved in this process. Moreover, the push of customers towards the market introduction of the product, namely from a foreign distributor, has defined the date of January 1999 to start selling the DDC. Production will start during the fourth trimester of 1998.

Specifically, there is one large foreign manufacturer/distributor working in the field of fire protection systems and elevators that is willing to reach an agreement with STEC Control for worldwide distribution of DDC system. This will undoubtedly push the sales figure, as we will see in next section. Moreover, this company has manufacturing capabilities and a commercial agreement to be reached may be ruled by a licensing contract valid for all countries in which they operate except for Portugal where we intend to develop our market share and brand. Other details related to this licensing contract can not be disclosed due to a confidentiality agreement.

The case that we have considered accommodating the electronics is according to standard DIN of different modulations. Next figure shows the geometry of this box, which has the equivalent of 6 module DIN corresponding to 105 mm. This case is suitable to be installed in the industry standard omega mounts that are widely spread in every electrical board used in the buildings.



The service of a mechanical designer has been subcontracted to develop this case. The foreign company as also included in their wish list the possibility to use this case in order to reduce costs and time-to-market.

Internal replication is guaranteed since future developments that are complementary to this project are already necessary. With the same electronics withdrawing the unnecessary parts, and possibly, with the same case, an expansion of inputs and outputs should be considered. An expansion module based on the DDC will be developed with 8 inputs and 8 outputs increasing the DDC to 64 inputs and 64 outputs.

Another development based on the DDC is the design of the inter-network controller that will responsible to manage communications and address each LAN of our DDC system. Other complementary modules have been already developed taking into account its simplicity of hardware and code, like the fan coil controller.

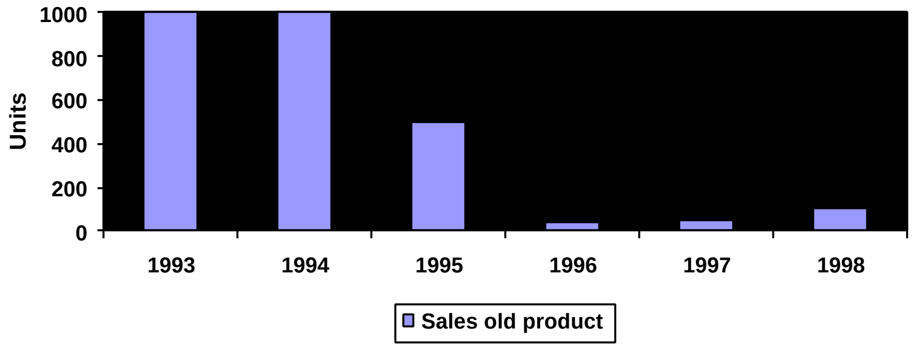
All the future developments will also be considered in the licensing contract between STEC Control and the foreign company.

Currently the tasks needed to industrialise the product are: the tooling and injection of a plastic case of DIN type for the installation of the DDC and EMC certification testing. These tasks have a total estimated cost of 25KEUR

16. Economic impact and improvements in competitive position

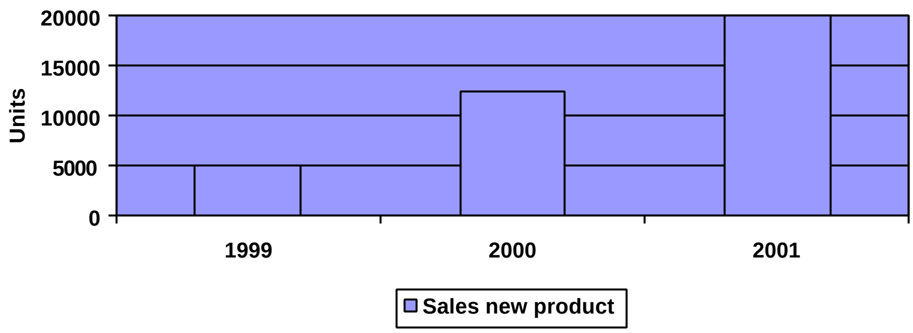
Company's knowledge about the actual market of building management systems is in a growing stage at this moment due to standardisation and international regulations on the field. There is a growing market from the demand side, yet from the supply side there is a very limited offer.

The new DDC presently proposed by Stec Control, intends to cover a wider number of applications than the existing products of competition already in the market. These products are usually not adapted for southern Europe specific climate algorithms. Factors of success like low cost, easy operation of the new controller, simple installation, clustered range of functionality, total control of its own developments are important at this moment to achieve a significant market share, especially on southern European markets.



The table above shows the sales figure for the last 6 years of STEC Control activity in the building management market. The first three years represent sales figures of our own analogue controller. In 1995 the analogue controller was obsolete and a replacement was needed for it to maintain our activity. As we said before we seek for alternatives in the foreign market in which we have found several manufacturers not all having the desired functionality. Still we have decided for a British company to supply the controllers for our activity in building management. Therefore, sales figure after 1996 only represent the controllers sold that were supplied by this British company.

The market for the new DDC controller is similar to the previous market where we used the English product. One of the goals of this application experiment has the intention to overcome traditional barriers of powerful building management systems but yet, costly and less flexible systems. The added value provided by the new controller is indeed, in its flexibility and simplicity of installation. The next graph shows our estimates for the DDC controller sales from 1999. Note that the estimates include the production of units for a large company as stated previously. These are conservative



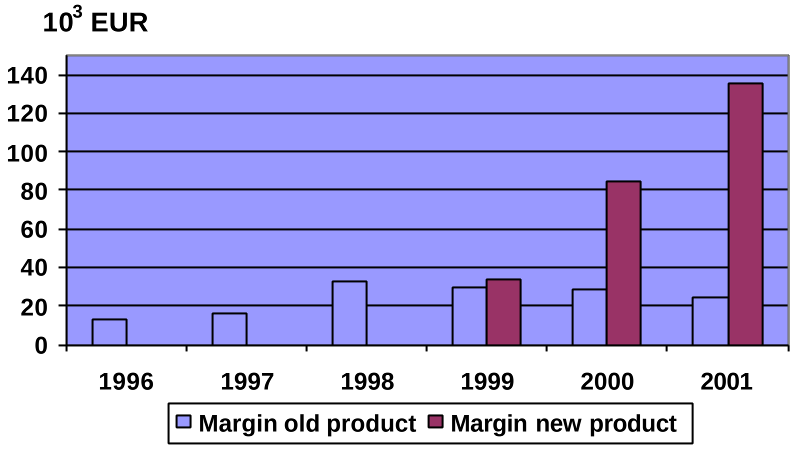
figures as we expect the market to grow in the near future.

The imperatives of the market have been changed since 1995, making prices to be low in the actual scenario. Moreover, to gain markets such as the home automation, scale economies are required to be successful in the market. Only a small components count in our new controller can provide us the ability to compete with cost.

From the actual position of STEC Control we will have to put some extra effort to develop our business as a supplier of hardware. This will be done through the development of a sales force and through the distribution channels. For this an important agreement with a foreign company has been reached to provide European (and worldwide) distribution, which allows us to predict that higher estimated sales figures could be possible.

The British controller used in the past years has an average sales price (depending on the configuration installed) of PTE 420.000$00 (2095 EUR). The margin given is 15% of total sales, which is related to the fact that STEC Control only distributes these controllers.

Although the margin for the new product will be lower (in absolute value) as well the price (below PTE 9000$00 – 45 EUR – depending on quantities), the new DDC provide innovative features that differentiate the product from other competitors and thus making the market to recognise its added value. These characteristics along with the fact that a commercial agreement with a foreign distributor will be established, will make us expect that volume sale will compensate the decrease of margin improving total revenues. The graph represents a comparison of the margin obtained from the British controller and the new DDC controller.



For the present project we had a total investment of 90,000 EUR. The table below shows that investment can be returned in a two-year period. The FUSE investment ROI was of 428%

FUSE	40	KEUR
Product industrialisation	25	KEUR
Marketing	25	KEUR
Total investment	90	KEUR
Company own investment on project	50	KEUR

Year	Cash flow/year (EUR)	Accu. Cash flow (EUR)
Invest. (98)	(90,000)	(90,000)
1999	33,750	(56,250)
2000	85,000	28,750
2001	135,000	163,750

17. Target audience for dissemination throughout Europe

The controller developed in this application experiment combines analogue and digital data acquisition with embedded software. The controller has the ability to work stand-alone or in a network with other controllers. Logical functions are performed by the software, which can read any physical unit and actuate producers or any other device.

These are the functions that could be seen in many usual applications making this controller suitable for any industrial area that requires control and the execution of logical functions. Such controller can then have the demonstrating power for companies in the same industrial sector (Electrical equipment – Prodcom 31) that are entering microelectronics for the first time, or any other company that requires control of its manufactured equipment, like:

- Precision Instruments (Prodcom 33)
- Tools and Machinery (Prodcom 29)
- Metal Products (Prodcom 28)

Unless directly involved in the control of a machine or any other device, this is a good example for process control. The controller can read sensors, combine and process them with logical functions, and decide to actuate the necessary device, which in turn could optimise the functioning of such process.

Areas requiring processing or control of physical units are agriculture, food and beverages, textile, glass and ceramics.

Industrialisation of DDC prototypes will require some changes and addition of features like:
- the use of an electro-luminescent display,
- four level inputs to cope with different uses (0 to 5V, 0 to 10V and 4 20mA),
- software programming of jumper features in prototype,
- and selection of components to provide more competitive cost.

This AE has lead to a successful new product that is an example to other very small companies with similar issues. The use of an independent consultant is also item to be stressed in replication events.

A plastic case of DIN type is also under development for the installation of the DDC.