The Development and Integration of Advanced Control and Monitoring Systems in the Built Environment

Contents

1. **INTRODUCTION**

This report:-

a) Discusses the integration of control and monitoring systems with advanced reporting networks employed in building services installations e.g. fire detection, HVAC controls, intruder and panic alarms, self-diagnosing/testing and exception reporting. These are appraised both technically and qualitatively on issues such as reliability and cost in terms of revenue and capital.

b) Investigates the opportunities available to the building owner for the use of multi-vendor ("open") systems together with the technologies available to help incorporate integrated systems to deliver reductions in capital and revenue cost and deliver improved services to the client.

c) Illustrates how I developed advanced reporting and self-diagnosing control and specialist monitoring systems, utilising the strengths of open systems and the operational advantages to both users and maintainers provided by integration of these systems.

2. AIMS

To demonstrate the following:-

a) basic control theory, including control algorithms relating to systems in the built environment;

b) types of systems available;

c) the advantages and disadvantages of current systems from a technical view point;

d) methods available for integrating systems utilizing single vendor or legacy systems compared with open protocol systems such as BACnet®, LonWorks® etc.;

e) the benefits, if any, of integrated systems in terms of:-
   i. reliability,
   ii. capital costs,
   iii. revenue costs,
   iv. opportunities for energy conservation, through connectivity benefits,
   v. introduction of full system logs to comply with controls assurance requirements,
   vi. self diagnosing systems to improve system availability,
   vii. self testing systems such as fire alarms, emergency lights etc.,
   viii. customer empowerment with respect to:-

      a. Local Control,
      b. Feed Back and Reporting,
      c. Interfaces

3. BACKGROUND

During the 1980s and 1990s electronic control and safety systems began to replace the earlier electro-mechanical systems, enabling more flexible control and monitoring of engineering systems, such as air conditioning. The earlier systems required craftsmen to visit site regularly; where as the newer systems allowed this to be done remotely more often allowing the customer to benefit from reduced maintenance costs. These continued to be installed as discreet control systems, typically monitoring and indicating alarms, such as fire, intruder and medical gas, for the building operator to action.

It has been normal practice for manufacturers to maintain their own systems due to their complexity, different configuration methods, and internal programmes that are often individually tailored to the manufacturer's requirements. It is often either not commercially viable for potential competitors to train their employees on a competitor's system, or the manufacturer has prevented the client or external maintainer from making system level or strategic changes to the installation by using passwords.

These earlier "closed" systems were often unreliable, partly because the manufacturers could not afford to properly de-bug the operating systems and programs. To improve reliability, manufacturers kept the systems capability and functionality as simple as possible, and integration of systems for these reasons rarely occurred.

I have had direct experience in the mid 1980s of the problems of reliability and inflexible systems at a time when PCs with Windows® operating systems were becoming more common in the mid 1980s. On my main hospital site a large BMS had been installed, which failed to work because the operating system was poorly written. This bankrupted the manufacturer. Another BMS on site from a major manufacturer was only a little more reliable, so with an electronics engineer I developed the software and then hardware to replace the BMS control and monitoring systems in critical areas of the site.

From the two failed systems and the problems encountered it became apparent that a BMS could work reliably and control complex building services installations provided:-.

- the control and monitoring requirements were understood;
- strategies were in place to reduce the impact of electrical interference; and
- field wiring issues were understood and resolved.

Initially manufacturers were slow to realise the commercial advantages of closed systems. Earlier electro-mechanical systems could be maintained by anyone with a good understanding of this technology. Clients were also slow to understand the true life cost of Building Management Systems (BMS) and other specialist control and monitoring systems, mainly due to the inability of accounting procedures to reflect accurate costs of capital projects, maintenance and upgrades. Companies were also unable to easily bench mark these "closed" systems with respect to their cost benefit compared to other alternative control systems.

Subsequently I established, there was little competitive incentive for manufacturers to further develop their products in the way that other industries, using similar technology, found necessary. An example of this is the in the automotive industry, where the integration of once separate systems is bringing marketing and competitive benefits.

For these reasons, “open” systems such as BACnet® and the LonWorks® Protocol were developed, allowing clients to develop with like minded integration companies, more flexible and often cheaper, innovative BMS and other specialist control and monitoring systems and bring these to the market place.

I became interested in the advantages offered by “open” systems in the mid 1990s; installing my first system in 1998. Since then, this initial pilot system has been extended and has been used in over 40 projects as part of my Health Trust’s capital program on numerous health care sites.

The development of “open” systems has allowed me to innovate numerous control and monitoring strategies and to integrate many BMS and other specialist control and monitoring systems.

The experience gained in implementing and operating integrated open protocol control systems over seven years has provided me the opportunity to research the opportunities and constraints applicable in the building services sector.

4. **TECHNICAL CONTENT**

4.1 Why use building control and monitoring systems?

Building control and monitoring systems are installed in buildings for a variety of reasons. These include:-

- To maintain comfortable working/living conditions (for the greater comfort of mankind[†]);
- to improve the productivity of its occupants and any process carried out in the building;
- compliance with legislation and standards;
- provision of a controlled environment for example:-
  hospital operating theatres;
  clean rooms (integrated circuit manufacture);
- to protect the building and its occupants against loss e.g. prevent damage to equipment, flood, loss of power;
- to minimise energy used;
- to minimise maintenance costs (including periodic alteration and refurbishment).

Ultimately the amount of control and monitoring installed in a building is determined by the legislative requirements and the cost effectiveness of the control and monitoring systems compared with the improvements in productivity and revenue costs for the building. For example by productivity improvements achieved when people work in a building with the optimal environmental conditions[1].

In general, the cheaper a given system is to install and run and the greater the benefit to the building owner and occupier the more likely it is that it will be installed. This in itself has the additional benefit that more examples of the system will be installed which therefore reduces the installation and maintenance costs further. In conclusion, if control and monitoring systems give the customer greater benefits with a reduced capital outlay, the more widespread their installation will be.

For the development and integration of advanced control and monitoring systems to be of use to building owners and occupiers, these techniques and systems must meet this objective.

4.2 Control theory

For the purpose of this report the most important aspect of control theory is the benefits of closed-loop control as opposed to open-loop control.

† Motto of the Chartered Institute of Building Services Engineers
[1] Wyon D P, Current indoor Climate Problems and there possible solution, Indoor Environment 1994; pages 123-129

In control, or for that matter management, it is much more desirable for the effectiveness of the process to be understood by installing a recording device downstream of the process being controlled as demonstrated by the diagram below

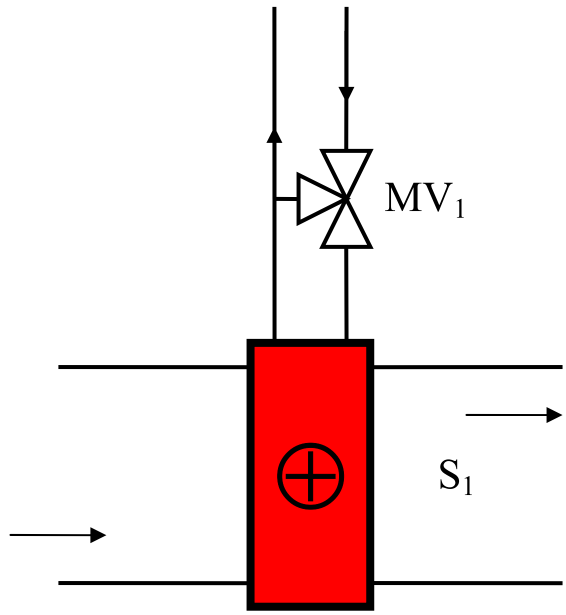


Figure 1: AHU heater battery.

Open-loop control is where the feed-back loop is not installed, and the control of the process is a matter of judgement, e.g. where a motorised valve feeding a heater battery in an AHU (Air Handling Unit) has failed and the maintenance fitter opens the bypass to regulate the flow of heat, in this case there is no feed back to adjust the valve to more closely meet the preferred temperature. An acceptable form of open-loop control is the time clock where plant is brought into operation at fixed times in the day.

In the case of control and monitoring systems and the installation of integrated and self-diagnosing systems these use wherever possible the “closed loop” monitoring/control techniques.

4.3 Types of systems available

Control and monitoring systems used in buildings often have similar base components. These include:-

- the collection of information from (input) devices, such as temperature and pressure sensors; and

- the manipulation of input information by using control algorithms to generate outputs to valves, sounders and other systems, etc.

The collection and utilisation of data is achieved by digital communications and use of microprocessors.

Control systems can be split into three categories:-

- closed systems (proprietary systems);
- open systems (such as LonWorks®, BACnet®), using open protocols;
- closed systems using open protocol to communicate between controllers, but using non-standard variable types such as temperature, speed, etc.

4.3.1 Closed systems

These comprise single vendor systems, such as most branded BMS excluding Honeywell, and the majority of fire alarm, medical gas alarm, security systems, etc.

Figure 2: Seven of 18 single-vendor alarm systems interfaces in a control room.

These systems all receive input data, manage data, and generate outputs to control equipment or provide information for people to act on.

Closed systems differ from other systems in that they are normally designed for one use e.g., BMS to control HVAC equipment, or fire alarm systems to detect and report on incidents. The communication protocols and operating programs have been developed for the sole use of the manufacturer’s workforce and agents.

These systems are relatively expensive to develop and enhance, compared with those utilising “open” system protocols as outlined below. The reasons for this extra cost are:-

- The communication protocols and language being developed individually by companies for use in their own systems,

- the operating programs whilst often using industry-standard programming languages are developed by companies for their own systems;

- programs used in “closed” systems tend to be simple and with fewer embellishments because:-

    - development and testing costs are borne by the individual manufacturer;

    - simpler systems are more reliable with less to go wrong;

    - training requirements for their service staff are reduced, both initially and for updates.

An example is medical gas alarm systems. These were developed for a specialist market, and due to the relatively large development costs have remained largely unchanged since the 1980s. The basic input device for the systems remains the pressure switch which provides a straightforward digital input to operate an alarm lamp in the event of an alarm condition (see Figure 3). Manufacturers have avoided the use of pressure sensors and more advanced programs to carry out “condition-based monitoring” of the medical gas supply systems e.g. by monitoring the rate of change in pressure of the supply cylinder manifolds to give early warning of supply systems faults and to allow more time to resolve these before the gas supply to patients is exhausted. (See Appendix 1 for discussion on the engineering fundamentals of this monitoring system).

Initially, Open systems were not employed by the larger BMS and control and monitoring system manufacturers, although recently they have begun to offer gateways to some of the open protocols such as LonWorks®, BACnet®, etc. (particularly those defined by international standards). The scope and quality of these gateways vary widely (see discussion on gateways below).

Figure 3: Single vendor medical gas alarm system interface-

Maintenance and servicing costs tend to be higher, as the majority of systems are maintained by the manufacturer with little or no competition for maintenance available from alternative companies. Consequently, there is little incentive to keep prices down. Where the manufacturer has appointed independent agents, the manufacturer still sets the software and component costs to the agents. In effect, a local monopoly exists as the manufacturer knows that the owner will have to pay again for new infrastructure for most replacement systems. Infrastructure upgrades make up a significant cost of system maintenance (as well as system extensions, and refurbishments).

Where there are significant benefits from integrating control and monitoring systems (e.g. fire alarm system manufactured by x being integrated with system y or a BMS to be integrated with complex plant such as large chillers), manufacturers sometimes develop gateways. These act as translators to convey often limited information from one system to the other. This benefits the manufacturers saving them the cost of developing control strategies from scratch and taking on extra risk for control and management of the other system of which the manufacturer may have little or no knowledge. The gateway converts one communication protocol and communication language of the host system to that of the receiving system. This often requires the development of new hardware and software with additional penalties of reduced reliability and in practice a limited number of parameters that can be sent through the “gateway” largely as a result of the time and resource needed to develop these more fully.

4.3.2 Open systems

Open systems are used in most types of building control and monitoring systems. They are also used in many other fields of engineering, such as transport, manufacturing, retail, domestic white goods, power industries etc.

Use of open systems across these industrial sectors (see Figure 4) helps to bring down manufacturing and programming costs as a result of competition.

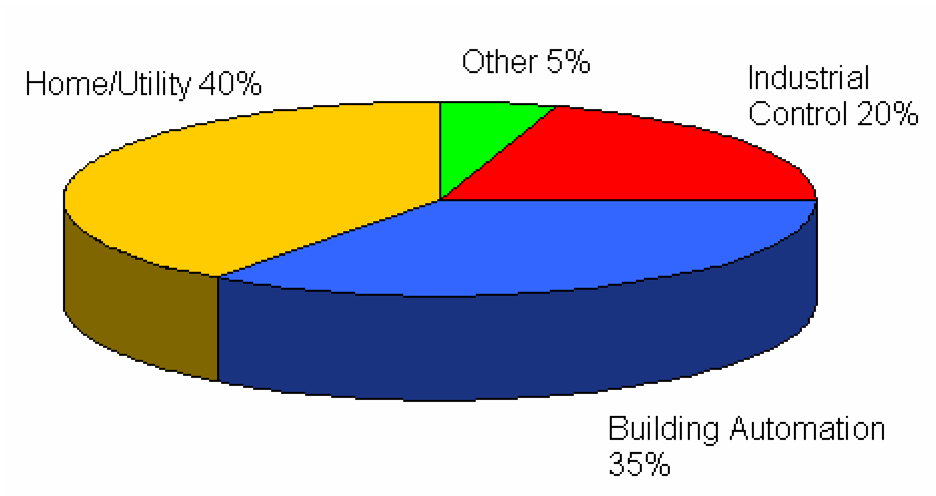


Figure 4: LONWORKS applications by market sector worldwide.

Open systems have evolved due to the high cost of developing bespoke operating systems, and because they have the potential for use in many industrial and commercial sectors.

The advantages include:-

- development costs are shared by many companies;
- alliances between companies to share control and monitoring program development costs;
- single large companies use "open" systems to provide common communications protocols and operating systems to bring together and offer significant development cost reductions for the many different types of control and monitoring systems they manufacture;
- single companies set up with the sole purpose of developing an open protocol for other companies to incorporate into their control and monitoring systems e.g. Echelon (LonWorks®);
- utilisation of ASHRAE standard protocol to enable the management and integration of building services e.g. BACnet®;
- systems using open protocols can be offered by many manufacturers and installers, and this makes the procurement of open systems nearly 100% competitive (often the only non competitive element being Licences);
- open systems are attractive to manufacturers because they reduce risk by utilising a widely used system operating within a defined international standard;
- development costs are reduced due to a greater pool of integrators familiar with the protocol from which to draw information. Code and control algorithms can be

shared between what were once considered different systems, e.g. intruder alarm systems with fire alarm systems, saving development costs;

- components are cheaper because of competition and much larger production quantities (spread over many industries);

- components and the embedded software are much more reliable and resilient due to their use in so many systems. Problems are reported and discussed openly and resolved, and because of this, people working with open systems tend to have more confidence in the protocol, feeling that as information is shared openly between more people than the would have been the case with closed systems, the risk associated with the discovery of a previously unknown problem is reduced;

- because open systems are used in many market places, manufacturers often co-operate to share development costs etc. because they are using the same technologies in different market places.

Honeywell is the principal major manufacturer to fully embrace open systems. Their interest in interoperability between their control system products led them to select LonWorks® as their platform;

Because the development and manufacturing costs are lower for a given product, more advanced control and monitoring facilities are becoming both cost effective and commercially available. This in itself provides an effective marketing tool for manufacturers to attract new customers. (See Appendices 2 and 3 where I have developed advanced control and monitoring techniques illustrating my understanding of basic engineering principals.)

With the exception of Honeywell, companies using open protocol systems as the back-bone of their control and monitoring systems have tended to be smaller, possibly because the large costs for the development and upgrade of closed systems would have impaired their ability to finance developments and be competitive.

4.3.3 Closed systems using "open" protocols

These systems offer a half-way house for some manufacturers who wish to retain control of their systems whilst reducing their development costs compared with closed proprietary systems. In the case of a LonWorks® system the manufacturer retains control by using non conforming Standard Network Variable Types[2] (SNVTs) this prevents other closed or open manufacturers using the LonTalk® protocol to access another closed system. Typically these systems are limited to use by a single manufacturer.

[2] LonMark® SNVT Master List Version 12 June 2003 Echelon Corporation

4.4 Requirements for an effective control protocol

This is best discussed by listing the desirable characteristics of a control and monitoring system protocol. Followed by comparing protocols, with respect to the more advanced and embracing open systems such as LonWorks®.

Any control protocol must meet several requirements, not all technical, e.g. they:-

- must work in the built environment;
- must be capable of easy installation on construction sites and occupied buildings;
- be simple and quick to commission and test;
- be easy to use, manage and maintain; and
- have the ability to be modified to encompass new developments and requirements;
- an open protocol that is freely available for any stakeholder to use.

Developing these requirements, the stakeholders would want an open protocol system to have the following characteristics:-

- high speed communications capable of passing the higher quantity of data generated from self diagnosing systems and system logs;
- reliable protocol, preferably backed up by an agreed international standard;
- a strong support organisation for integrators, designers and clients;
- a protocol that can handle priority messages (e.g. for life safety systems);
- a protocol that can handle acknowledged messaging (i.e. it confirms receipt of information packet), these need to confirm a communication path is healthy between two points, often controllers, and that the frequency is adjustable. This is particularly important for systems fulfilling more "mission critical" tasks or utilising more advanced self diagnosing techniques these also work better with protocols operating at higher band widths;
- a protocol that allows the customer to minimise the impact of component failure, e.g. allow cabling and routers to be installed resiliently for critical systems, and for the installation of smaller controllers to be economic so that the failure of a controller does not result in significant loss of facility;
- a protocol that allows many systems, perhaps installed by different integrators, to use the same controller and network at the same time;

- for there to be no more than a small charge for licences or other payments direct to the developer of the protocol;

- for the protocol to permit the use of network-powered control devices. E.g. by the network powering detectors, sensors, speakers, lights (emergency) etc. therefore allowing manufacturers greater freedom to provide imaginative flexible products;

- for the protocol to be widely used. E.g. not only in building services but in other market places, e.g. manufacturing, domestic and transport;

- for the protocol to allow networks to be arranged to suit the most convenient cabling installation and for controllers to be available in a variety of sizes again to suit site conditions;

- for the protocol to be transportable over several communication paths, e.g. shielded or unshielded Twisted Pair cable, infra-red, radio, fibre optic, power line, etc.

- be suited for use with all types of building services control and monitoring systems and not be designed primarily for HVAC or manufacturing, as with Modbus®;

- have all major components e.g. controllers, routers etc. available from many manufacturers.

An open protocol used for control and monitoring systems, needs to meet many requirements both technical and non technical, and all aspects need to be satisfied for its use to be practical and economical and to meet the needs of all stakeholders particularly the end-use client.

The customer has many protocols to chose from but very few fulfil all the characteristics above (See Appendix 5 for an abbreviated list of open protocols, also known as field buses).

It is not the purpose of this technical report to objectively select the optimal protocol as these may vary according to each organisation's needs. The more popular protocols, such as BACnet®, KNX®, and LonWorks® all meet most of the criteria above, though I believe when I started to install open protocol systems in the late 1990s the system that best meets the requirements of control and monitoring systems in the healthcare field, particularly for integrated and advanced monitoring systems, is LonWorks® with their LonTalk® protocol.

A short discussion of principal differences will high-light why careful selection of protocol is important when linking to proprietary, or installing, new control and monitoring systems.

4.4.1 Comparison of BACnet, KNX and Lonworks

4.4.2 BACnet

Strengths:-

- scalable: a complete communication protocol for the management, automation, and field levels;
- completely open: manufacturers can implement the protocol without any licensing fees;
- specifically designed to meet the needs of the building industry;
- being established as a world standard through ISO and other bodies. No other protocol is under consideration;
- constantly evolving: Built-in mechanism for updating and enhancing the standard through industry consensus (although this may also be a disadvantage);
- there is no vested interest controlling the development of BACnet.

Weaknesses:-

- no standardized programming language: proprietary programming tools must be bought from each manufacturer;
- no standard configuration tools: proprietary configuration tools must be bought from each manufacturer;
- expensive for manufacturers to develop;
- BACnet is a written standard that is subject to interpretation by manufacturers: the manufacturer has to write his own operating system to comply with the standard and this is both expensive and liable to need debugging, giving rise to many of the disadvantages associated with “closed” systems.

4.4.3 LonWorks

Strengths:-

- widest implementation over a wide range of applications due to early entry into market;
- standard programming tools;

- simple for manufacturers to implement through standardized tools and because the protocol is pre-configured on the neuron chip;
- has power line carrier RF (Radio Frequency) and IR (Infra Red) implementation- BACnet does not;
- all Lon solutions require multiple software packages to configure the system, such as Lon Maker, Visio, and OSS2000 These are all lower cost programs than most rival systems;
- Lon is a technology that complies with the standard written after it was put into use. The technology is replicated in all neuron chips, whilst this reduces competitiveness (see weaknesses); this technically is a strength as only one set of software bugs would need to be rectified, reducing overall expenditure.

Weaknesses:-

- not scalable. Limited by speed of the Neuron chip;
- limited facility for programming complex routines or large algorithms such as advanced self-diagnosis and careful programming is required (alternatively use external processor can be used for advanced function);
- licensing fees built into the cost of LNS (LonWorks network services) and neuron chip payable to Echelon;
- proprietary hardware. Neuron chips must be purchased with a licensing fee to Echelon;
- LNS network tools are proprietary and must be purchased from Echelon Corporation.

4.4.4 KNX (EIB European Installation Bus)

Strengths:-

- designed for ease of installation and commissioning, and is best suited for simple control applications for this reason;
- KNX standard now expanded to incorporate operation over Ethernet.

Weaknesses:-

- KNX is popular in Europe as a field bus protocol in the building industry but has not been visible outside that region;

- KNX was initially developed for the field level with a data signalling rate of 9,600 bit/s. A faster speed is available, but is not offered to CENELEC for incorporation into standard;

- power supply polarity sensitive.

This is a far from exhaustive list, but it serves to demonstrate that careful selection is needed. (also See Appendix 5)

My experience and developments in installing integrated and advanced monitoring systems have all been based on using LonWorks®. Most of the control, monitoring and management techniques I have developed could also be achieved if any of the other major open protocol systems available were used.

4.5 Methods available for integrating systems utilizing single-vendor or legacy systems compared with open protocol systems such as BACnet®, LonWorks® etc.

4.5.1 Integration by Network Sharing

In the controls field there are several meanings that can be applied to integration. In this case, integration by network sharing is where several individual systems are combined typically through “gateways” so that each system can be viewed at a PC screen(s). This is inconvenient for the user to get an overall view of the systems a number of interfaces have to be visited. Systems can be integrated (so they can be viewed on a single screen) often at great cost. Often information from one system has to be entered into each of the other systems and updated as the building use changes over time. The separate system “head ends” often share little information between systems, but when information sharing takes place this will normally be through a PC or Server resulting in a potential single point of failure if the PC or Server breaks down in this example, apart from being inconvenient, any alarms generated will not get through. The figure below shows integration of various open type systems, but these could easily include fire alarms and other specialised systems, in place of say the BACnet® sub-network.

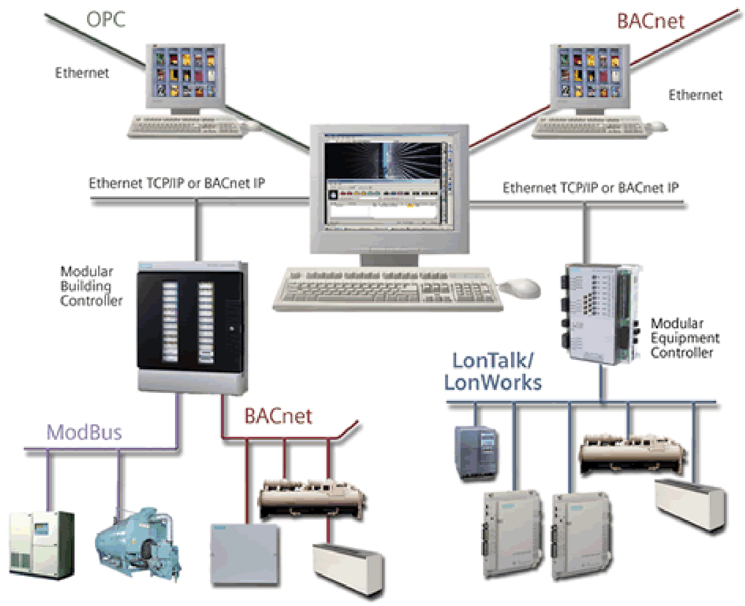


Figure 5: Integration by network sharing, gateways connect the control networks to the TCP/IP backbone.

This method of integration relies heavily on gateways where each control and monitoring system is supplied by a propriety manufacturer. Gateways tend to be limited in the amount of information they pass on. They also have the following weaknesses:-

- unless there is redundancy in the system each gateway represents a single point of failure;
- as can be seen from figure 5 above, having less gateways, increases the communications cabling required as each sub-net has to be wired back to the nearest gateway for that particular system. This tends to increase costs;
- gateways between proprietary systems are uncommon as the manufacturers can alter their protocol without reference to others, potentially rendering the gateway dysfunctional or inoperative. Gateways are more common between proprietary systems and open protocol systems that have an international standard defining their make up e.g. LonWorks®, BACnet®;
- gateway Programs from proprietary communication protocols tend to be less well written and less reliable than those from defined open systems and defined communications protocols (e.g. TCP/IP) because of the relatively small manufacturing quantities for these;
- as will be discussed later, this type of networking/communications arrangement tends to be more expensive and less reliable than the defined open systems.

Figure 6: Grundfos pump G10 Lon gateway between manufacturers and LonTalk protocol.

Due to the limitations above, limited ability of gateways and the comparative inexperience of manufacturers integrating their systems with others, most limit their integration to using volt-free contacts to exchange information.

4.5.2 "Fully integrated" systems

A system that offers many more opportunities is the "fully integrated" system, where control and monitoring information is shared directly between controllers; PCs being mainly used as a management tool to make modifications and receive information from the system. Figure 7 illustrates that control and monitoring systems are similar in that they all have:-

- Inputs;
- Input information, data processing, and the result being sent to;
- Outputs.

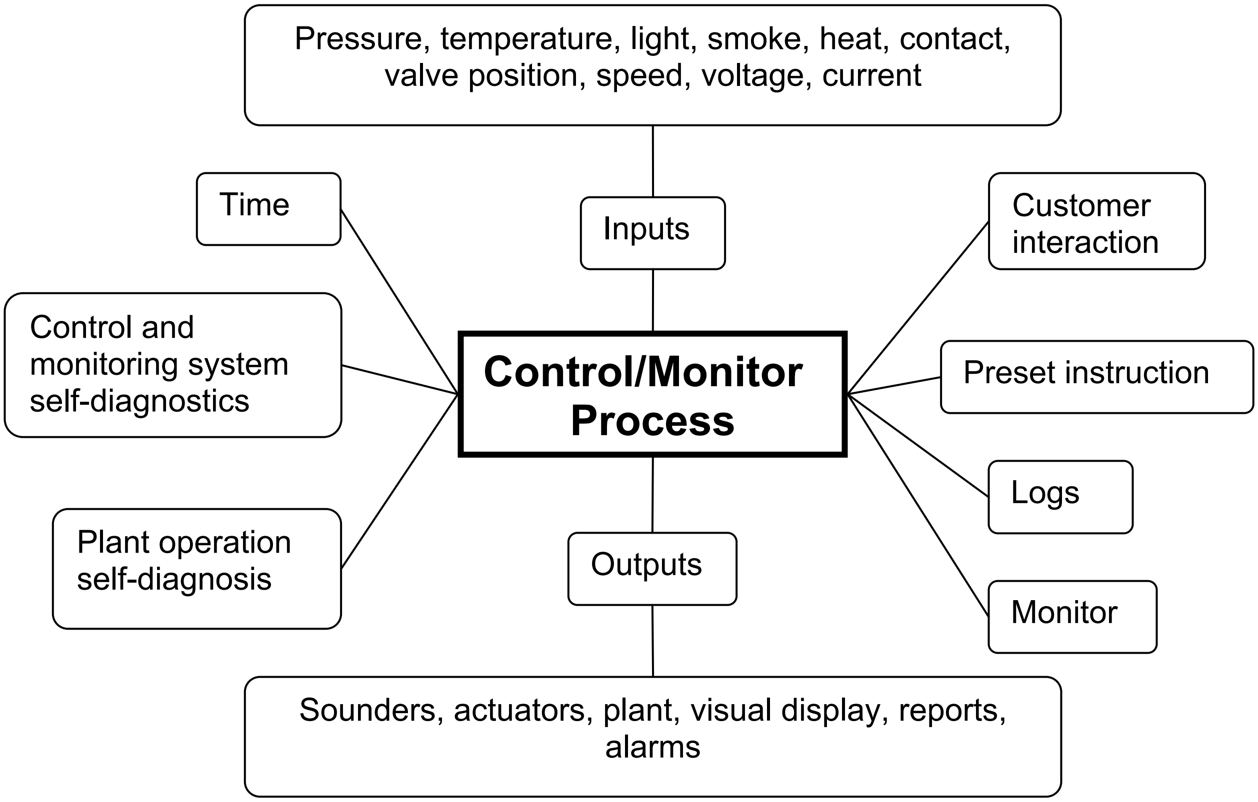


Figure 7: Principle relationships of control and monitoring systems.

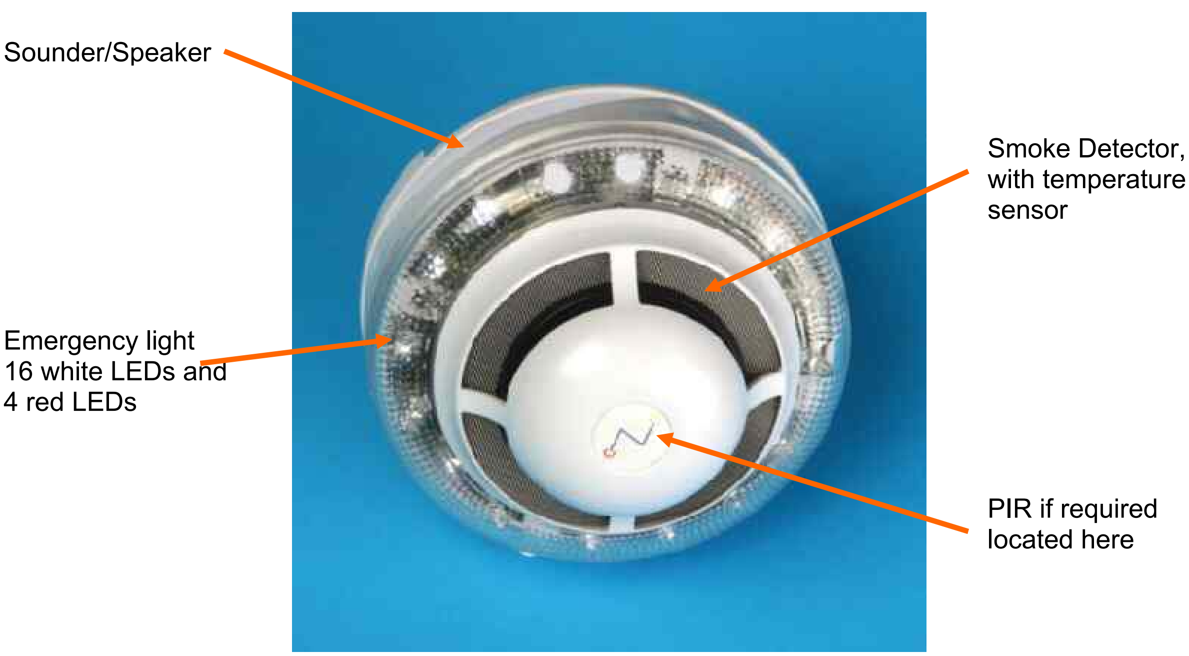


Figure 8: Integrated controller, containing many input/output devices. courtesy Zytron

This method of integration is still in its infancy, there being few protocols that can support this level of integration, and no single proprietary systems manufacturer provides a fully integrated solution. (See Appendix 2 for a practical example of the integrated systems.)

With this method of integration, input/output devices are connected to controllers which control and manage the flow of information from what would traditionally have been separate systems. In many cases an input/output device or sensor information is used for several purposes. For instance in a building, many input/output devices such as temperature sensors and passive infra-red detectors, are often duplicated, because they individually control plant or provide information for other systems. This duplicates wiring and components which have to be individually commissioned and maintained.

With integrated systems, a controller receives information from sensors and/or other controllers and provides outputs to further controllers and/or devices to achieve the desired action. (The controllers do not belong to a particular system.) The advantage of this is that they are located closer to the input/output devices. This has the additional benefits of requiring:-

- Fewer physical input/output Points,
- Fewer controllers,
- Less cabling,
- Simpler and fewer networks.

The following are examples of integrated devices:-

A passive infra-red detector in a room can be used to:-

- turn on the heating or ventilation systems;
- indicate the presence of an intruder;
- turn on the lighting in the room when occupied.

A sounder in a room can be used to warn of a:-

- fire;
- patient call;
- intruder;
- attack;
- other security situations;
- process equipment malfunction;
- high/Low temperature;
- open door (controlled environment);
- or any other audio output.

At the display and head end of the control and monitoring system there are further integration benefits when using:-

- enunciator panels;
- displays;
- head end PCs.

These are often combined e.g. in the healthcare field, I have done this with surgeons' control panels, environmental condition, fire, emergency power, staff to staff call etc. all replacing individual lights and sounders from numerous independent systems with a single wall mounted touch screen PC.

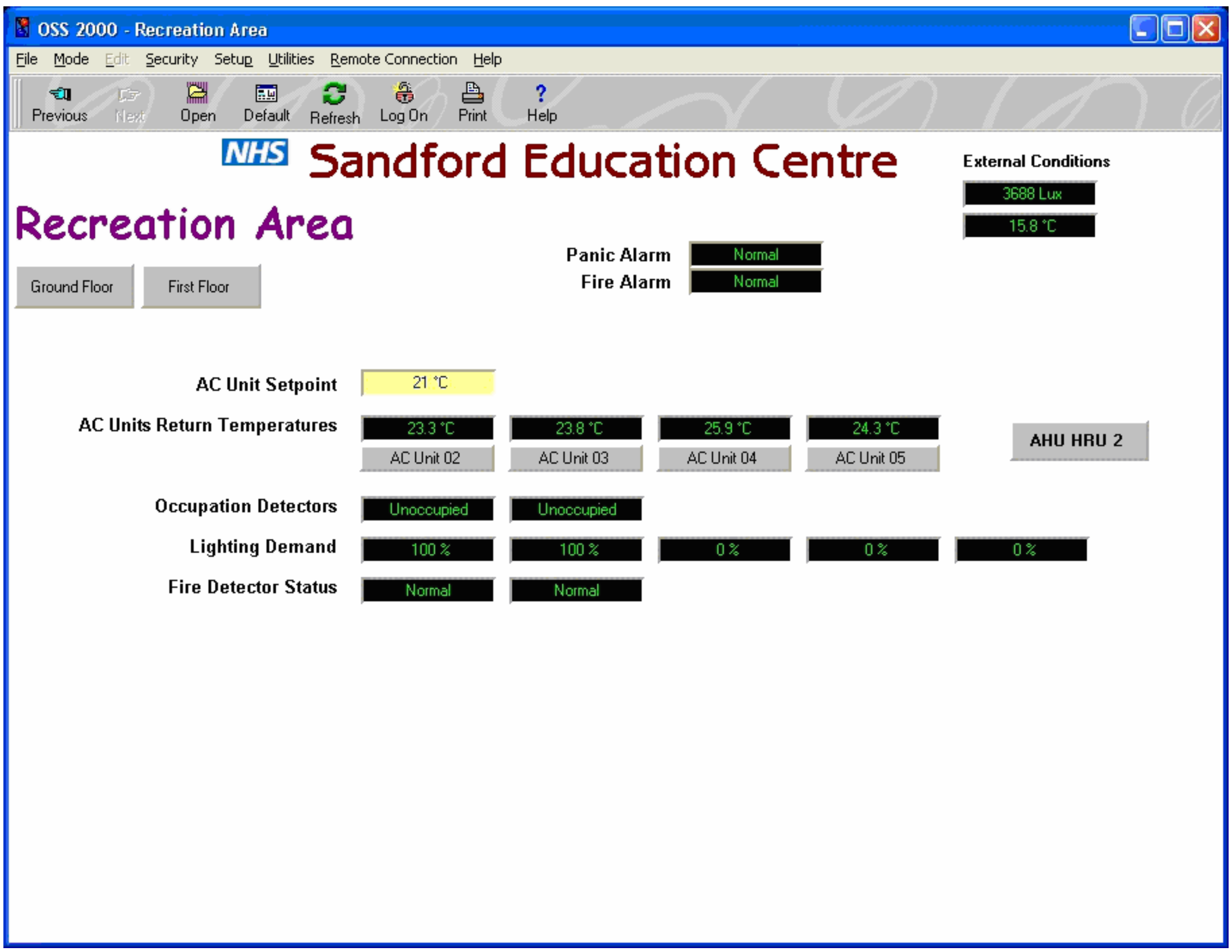


Figure 9: Status of numerous systems in one room on one slide

With stand alone alarm systems each has its own display system. To obtain information on conditions (fire alarm/security/environmental etc.) in a particular area would require perusal of many monitor screens or wall mounted panels. This would also be the normal method of viewing by the "Integration by Network Sharing" technique in the event the systems are not fully integrated.

With the fully integrated technique, the data uses the same control protocol and this makes it much easier to view all the conditions in a room of part of a building from one “web” page. While at an alarm enunciator panel instead of information from one system, information from many systems is displayed e.g. intruder, panic, assistance, patient call alarms etc. see figure 10.

Figure 10: Picture showing integrated alarm system interfaces. Seven once separate systems are accessed and monitored from these screens.

With the proliferation of alarm systems in buildings (see Figure 2) one of the emerging problems is confusion caused by the many similar sounding alarm tones and pitches used by the numerous manufacturers of systems. With the integrated approach many once separate systems are often provided by a single manufacturer who co-ordinates the types of sound used to communicate a given alarm (compliant with standards where specified e.g. BS 5839:2002[3] and HTM 2015[4]).

4.6 Cable and Component reductions with integrated systems

Fully integrated systems have other benefits, because controllers share input/output devices even when used for notionally different purposes. This reduces the average cable length from the input/output device to the controller. Cable savings are further enhanced by the quantity of devices being reduced by sensors being shared by the combined network and controllers.

[3] *BS 5839: Fire detection and alarm systems for buildings: Part 1 2002. Code of practice for system design, installation and servicing* (London: British Standards Institution) (2002)

[4] HTM 2015 Bed Head Services Design Considerations HMSO 1995

With even the simplest office building five control and monitoring systems are typically required:-

- fire alarm;
- intruder alarm;
- temperature control;
- lighting control;
- emergency Light.

When these control and monitoring systems are integrated, the network and sensor cable savings are significant, Figures 11 and 12 clearly illustrate this.

Often this list of essential services would be added to with:-

- access control,;
- time and attendance;
- personnel alarm;
- metering;
- door entry;
- CCTV control systems, etc.

- industrial, Process Management;

- healthcare, medical gas alarm and system management.

In other industries, integrated systems have similar advantages e.g. Transport, Train operation and management systems.

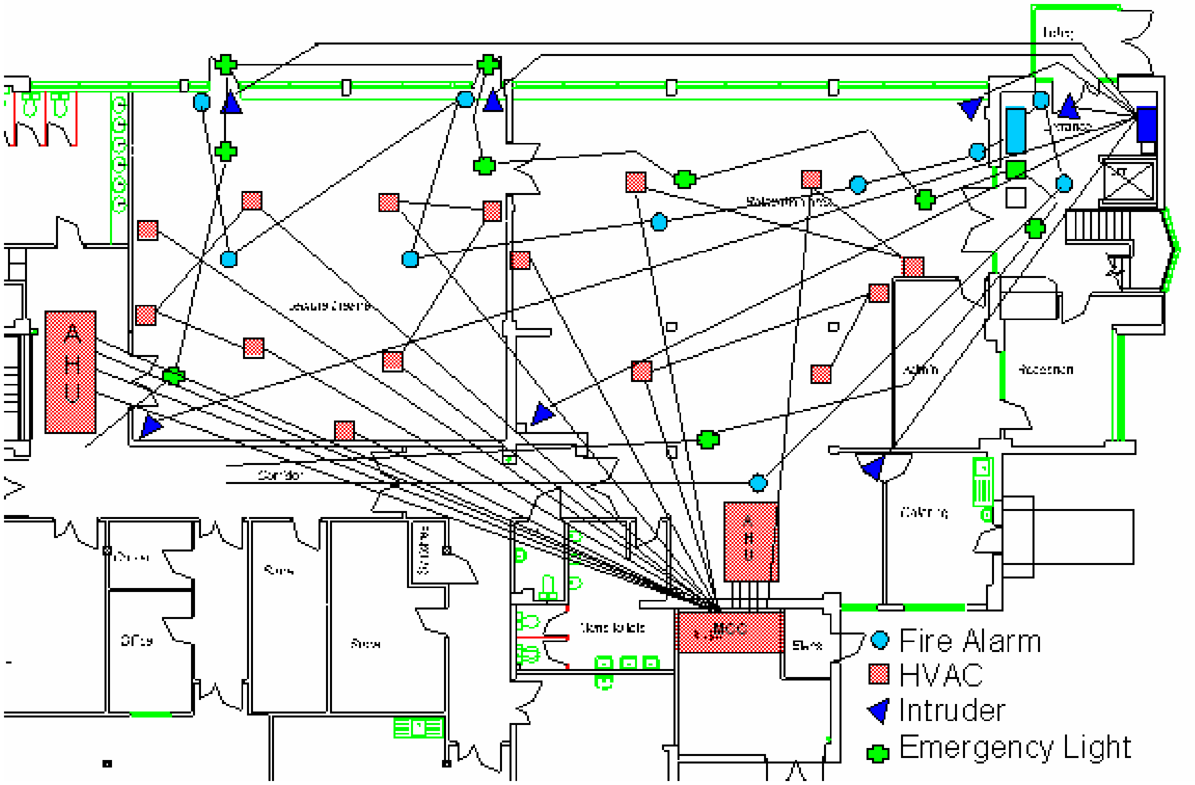


Figure 11: Traditional cabling installation for control and monitoring systems (normal lighting and some BMS control not shown).

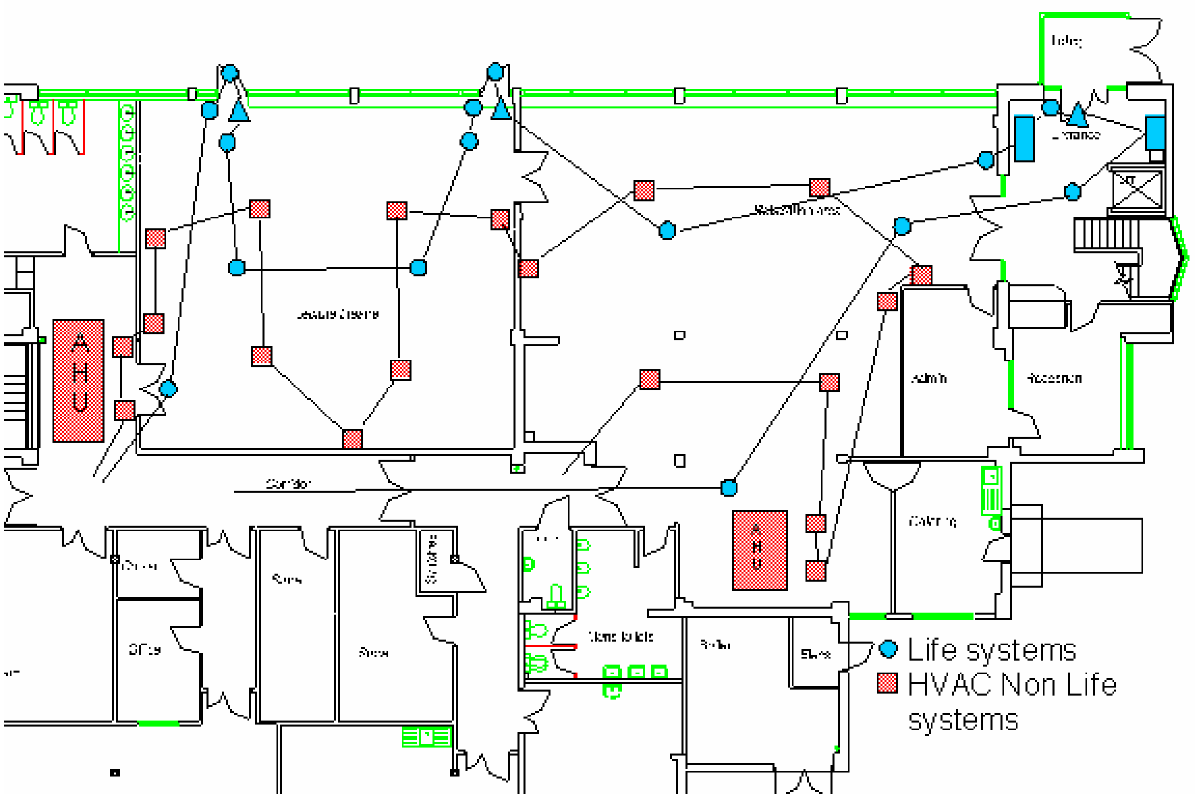


Figure 12: Integrated cabling installation for control and monitoring systems (normal lighting control not shown).

With other systems, network cable length, between device can be a problem typified by medical gas alarm systems using RS 485 communications technology. Even in a small district general hospital signal strengths become very weak and communications unreliable. With these copper cabled networks typically utilising one of the “open” protocols, the limits on length are normally 2400m or 400m utilising “free” topology. These distances are rarely exceeded, because the density of input/output devices is much higher than the non fully integrated systems. Band width of these “open” systems is in the range of 78kBits/second (some proprietary systems today still run in the range of 3.6kBits/second). These have the advantage of allowing the designer to choose the most economical location for the router (LonWorks®), or network controller (BACnet®) for connection to the high band width TCP/IP network. Most buildings already have a TCP/IP network, and the required band width for even a well developed building control and monitoring system is small (typically peaking at CGH 30 to 40 kBits/second for a Lon twisted pair network with a high proportion of acknowledged messaging) in comparison to commercial office data requirements. Using the TCP/IP networks saves further cabling costs.

Why not just use TCP/IP Ethernet to do all communications between controllers, head end, and other display screens? This is used on some proprietary BMS systems e.g. Satchwell Sigma. Technically this method works but has some draw backs, including:-

1. the controllers/outstations used tend to be larger as a result of the cost of incorporating a “gateway”/Router to connect TCP/IP;

2. because the outstations can accommodate a larger number of points the average cable length to the sensors etc. is longer and more costly than a more integrated approach. (see Figure 11)

TCP/IP was primarily designed to move large quantities of data between points and is not designed for the control data traffic between controllers/outstations. This solution is still attractive to manufacturers of systems that have their own network systems running at a slow speed, as converting to TCP/IP avoids the cost of developing a faster network between controllers. For control and monitoring systems the ideal network should convey relatively small packets of data, quickly between individual controllers and other remote applications. For this reason systems designed to handle small packets of data perform well e.g. KNX® and LonWorks®, network speed also helps reduce controller reaction time. In the case of LonWorks this is solved by the installation of “sub-networks” between controllers. Links to other “sub-networks” and more distant controllers/applications typically being performed by routers typically to TCP/IP networks.

Note: TCP/IP works better with long packet lengths not the smaller packets originating from individual controllers. With controllers accessing directly on to TCP/IP this can generate unnecessary extra traffic. This can cause problems on heavily used networks often impacting some time after installation.

In some installations, it may not be possible to install or connect to a TCP/IP network either for security reasons or there being no network. The control networks communications traffic can be sent using many other methods. LonWorks® for example is particularly strong allowing the protocol to be transmitted via:-

- Fibre optics
- Twisted Pair
- Infra Red
- Coax
- Power lines
- Radio

These methods of communication have been used where no other suitable network exists as illustrated below:-

The data for several million electricity meters in Italy is collected via power lines. In addition information from the meters in the homes of participating customers is used to limit power usage by controlling Lon devices in heavy power consuming equipment principally “white goods” such as washing machines, dishwashers, etc. to date 27,000,000 Neuron® devices are in use for this application.

In historic buildings, utilising radio and communication over power cables, LonWorks® avoids installing communication cabling.

4.7 Resilience and Risk

One of the reasons given for not using “open” and fully integrated systems is that if the network breaks down, more systems will be lost. This is not the case.

In a hospital for example there are typically over 20 control and monitoring systems, often maintained by as many companies. The Trust uses numerous maintenance companies to maintain these systems. The Trust often has no choice but to use the manufacturer of the proprietary systems. These manufactures are often not able to attend to the fault as quickly as the Trust would like, but it has no choice, because of the propriety nature of the systems. Even with the newer proprietary systems service is little better. On the other hand it is not practical or possible for the Trust to employ staff to maintain these systems because of the sheer number of systems and therefore staffing costs. The resources needed for each system would include:-

- Time/Money
- Training,
- Test equipment,
- Supplies of spares,
- Knowledge,
- Experience.

If the number of systems were reduced by using fully integrated system techniques, the typical number of control and monitoring systems falls from over 20 down to two; the controllers sub network e.g. LonWorks®, and the TCP/IP network. The relatively large TCP/IP network is already maintained typically by the organisations’ IT department. It can clearly be seen, that it is quite viable for most organisations to be able to directly employ their own specialist familiar with a single system. For the controller network it is now feasible to resource the expertise and test equipment to maintain this.

Do TCP/IP and controller sub networks fail at the same time?
The answer is rarely, if ever. TCP/IP and by definition controller sub networks are formed from separate smaller networks or segments connecting switchers and routers (as required) to make up the buildings' or complexes' wide area network (WAN). The switchers and routers act as isolators in the case of a failure. The way TCP/IP networks are normally installed in organisations makes this backbone more resilient. Because the organisations' IT usage is essential to its operation, networks between building and departments are made resilient exampled by the installation of secondary links in case of a failure. These also help the resilience of the integrated control and monitoring systems.

At the control network level in the case of LonWorks®, these sub networks can also be made more resilient, by installing the network in a loop and having a router at each end. However if the controller sub network fails the control and monitoring between controllers would also fail but an alarm would be raised to warn of the problem.

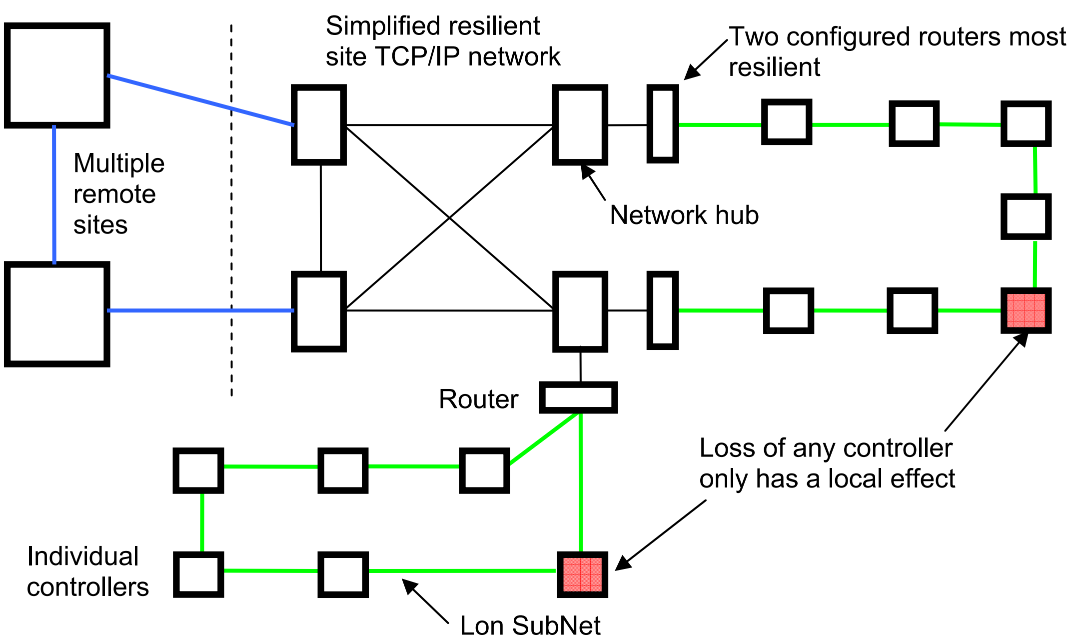
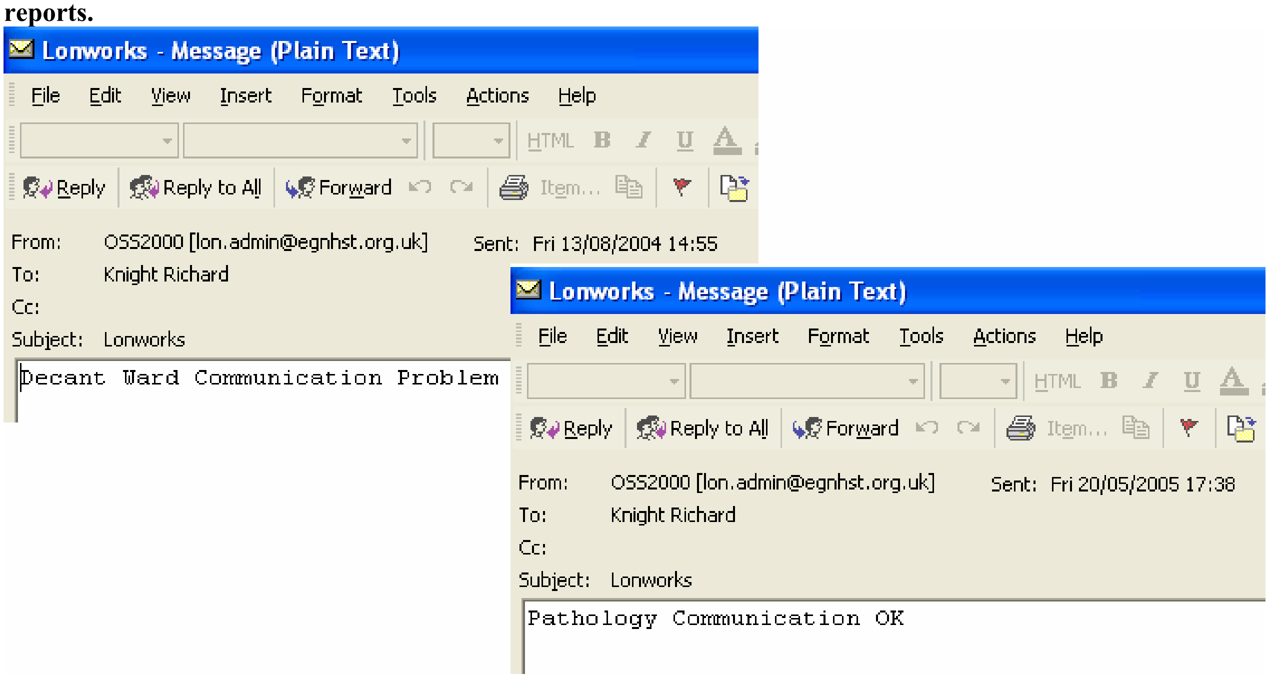


Figure 13: Resilient TCP/IP network to many sites with two methods of creating resilient control and monitoring sub networks.

How likely is a controller sub network to fail with the loss of connectivity between controllers, assuming there is only one router connecting the network to the rest of the communications network?

I have monitored this over the past four years. The method of monitoring is by sending regular messages from a controller on a subnet to a controller on another subnet. If the messages do not get through for more than five minutes in a 24 hour period an email confirming the failed sub net is generated by the controller, via the head end PC. An email is also generated if the sub network remains healthy. This is repeated to give a complete picture of the networks health (this also validates the operation of the TCP/IP network). Based on the above criterion a LonWorks subnet might fail once in six months. Of the remaining down times, these are caused by planned installation and modifications to the network, both at sub net and network levels.

Figure 14: Network health reports.



The main causes of failure tend to be cable breaks or controller breakdown. Both would result in some loss of connectivity and function of the system(s), but as indicated above the organisation is more able to resource a quicker repair, reducing the effect of a loss to less than with traditional systems.

4.9 Integration of building services control systems with other specialist engineering control, monitoring and reporting systems

In the early 1990s i was able to develop basic integration techniques as a part of the design phase of projects. At that time I linked the operation of radiant heating in a workshop with the setting and un-setting of an intruder alarm utilising volt free contacts, allowing heating to be available when the building was occupied (during call outs and out of hours repairs). This was about the limit of integration at that time without a very much larger budget to develop bespoke programs.

With the advent and use of “open” protocol systems the opportunities for integration were not obvious. I continued by integrating the access control and intruder alarm systems with the operation of heating systems much as before but taking advantage of the “logical” connections offered by integrated communications. These also gave other benefits. From a single integrated network in a small building, it was economic to connect this to the TCP/IP network and provide remote access to the building services, access control and intruder alarm systems. This allowed a common access control data base to be setup for the access control systems, only requiring one data base to be kept updated. There are other systems that have similar benefits including:-

- time and attendance systems;
- cashless vending systems;
- asset/personnel location systems.

Vending machine management and small scale catering (typically petrol station forecourt) systems; these are used for stock level/replenishment management, controlling pilfering, maintenance management. In these cases an “open” protocol system LonWorks® is being used in the development of these because of its strengths for control and ease of conversion into other transmission protocols such as TCP/IP and mobile phones for transmission to base.

I have connected Smoke damper control and reporting systems to “open” networks, allowing exception reports to be generated if any dampers close incorrectly. The dampers are closed when required by the fire alarm (if this is integrated) and co-ordinated with the location of the fire. I have installed this facility on larger ventilation systems, because the dampers are networked with the AHUs, it is much easier to program shutting down the correct plant in a fire as the plant run signal is conditional on the fire dampers associated with the AHU being open. The operation/condition of the fire dampers is accessible from PCs by the fire brigade/maintenance etc. This user interface is easily modified to take account of any changes, and the screen is also much more user friendly especially to the fire fighters than the more common engraved panel with LEDs and buttons with a framed plan to the side.

This lead to the integration of various alarm and monitoring systems and user interfaces utilising LonWorks® sub-nets and TCP/IP backbone WANs, including:-

Panic Alarms,

Disabled WC alarms,

Nurse Call systems,

User/maintenance interfaces at all PCs in the Trust

User/maintenance interfaces through wall mounted touch screen PCs have been used in:-

- hospital clinics for:-
    - nurse call systems;
    - plant alarms;
    - general alarms.

- operating theatres for:-
    - staff/staff call;
    - plant alarms;
    - general alarms;
    - environmental conditions.

- wards for:-
    - nurse call systems;
    - plant alarms;
    - general alarms.

- specialist pharmaceutical facilities for:-
    - room pressurisation conditions;
    - room pressurisation alarms;
    - room temperature conditions;
    - HEPA filter operating conditions;
    - HEPA filter alarms;
    - fridge condition and alarms;
    - plant alarms;
    - energy usage.

Through any networked PC, other systems include:-

- Electrical services management

- Electrical metering including PF, MD, THD, etc.

- Fire alarms, emergency lighting installations, etc.

These are in addition to the more usual building services controls.

In the most part these systems improved communication with the users empowering them to control, observe, and monitor their own environment and systems. This also saved significant cable costs by using a common communications protocol. These are all good examples of “integration by network sharing”. Over the years this has visibly reduced the number of system network cables running through main services ducts, linking major buildings, (see Figure 18).

Figure 15: Many separate system networks consume valuable space.

Since then I have briefed and managed the installation of more highly integrated projects. The following systems were integrated on the same networks:-

Building services

- mechanical HVAC plant control;
- medical gas alarm;
- fire alarms;
- emergency lighting installations;
- panic alarms;
- intruder alarms;
- door open alarms;
- disabled WC alarms;
- door bell;
- nurse call;
- emergency lighting;
- lighting control, including daylight linking;
- etc.

Integration of the above systems is further discussed in (Appendix 2 where I detail how I applied engineering principles to fully integrate control and monitoring systems).

4.10 Social benefits,

Fully integrated control systems deliver more benefits to the system users in a number of ways. These include:-

- User interfaces, being cheaper and simpler to use, can be made available to the end user at their PC or at a wall mounted touch screen PC where simple to understand graphics can be used in a web page format. In addition help, or advice screens can be incorporated to advise and assist the user;

Figure 16: Traditional hard wired surgeons panel.

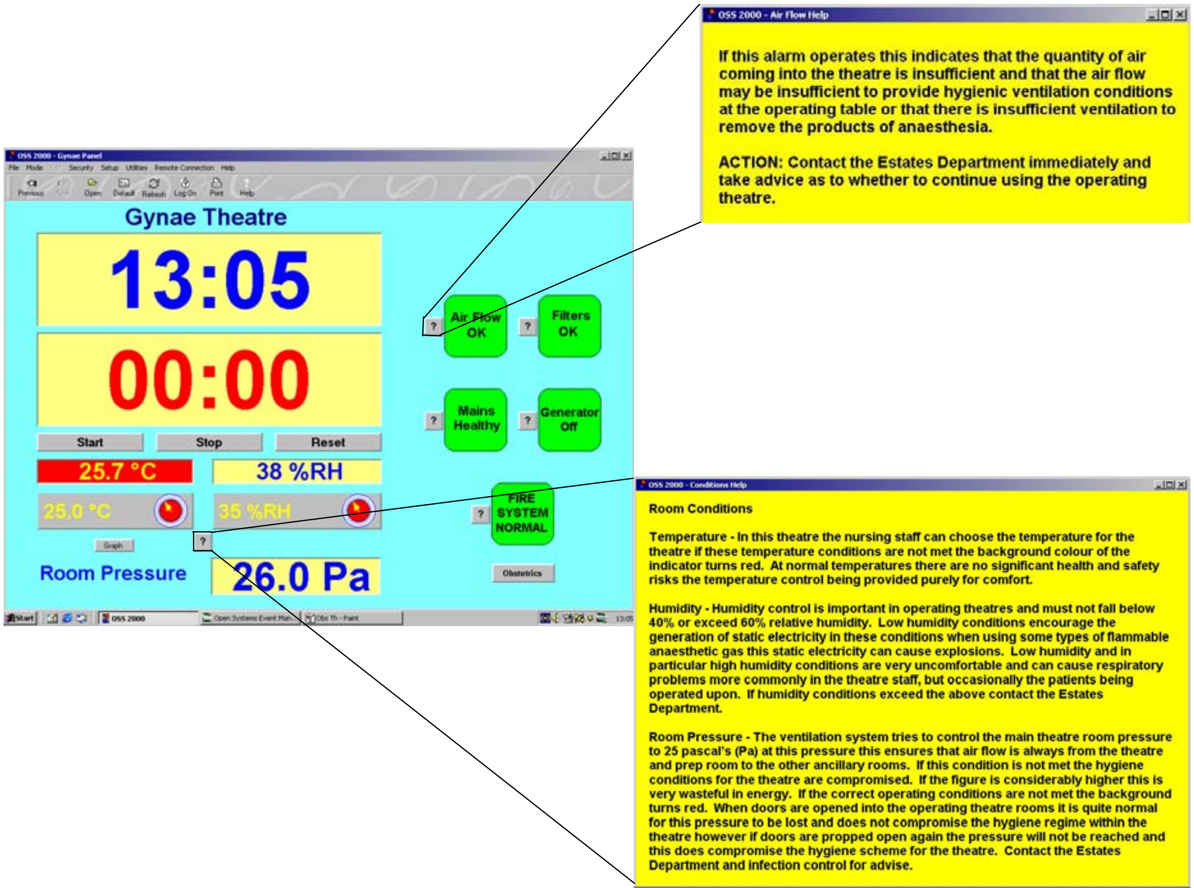


Figure 17: Integrated surgeons panel (from wall mounted touch screen PC).

- Increased capital savings with integrated systems. The provision of more local control is now more cost effective, providing greater control as discussed in the previous paragraph but also improving the end user's satisfaction with the system.

- With self-diagnosing routines, faults with the building services within a building are detected much earlier resulting in higher system availability and therefore a reduced number of complaints (also see Appendix 3 for a practical application of engineering principals for the self-diagnosing technique).

More reliable and more maintainable communications offered by "open systems" with self-diagnosing algorithms allow additional benefits in the improved functionality of "life safety systems". In the case of "life safety systems" e.g. fire alarms, emergency lighting, medical gas alarms etc., communications reliability is paramount. The more reliable and maintainable communications results improved availability and better monitoring of medical gas systems, making management of plant problems much easier, benefiting the patient with a more reliable supply of medical gases (See Appendix 1 for more detailed information on how I utilised fundamental scientific principals to this).

4.11 Reduced installation and commissioning requirements for integrated systems

The installation of control and monitoring systems in buildings makes up a significant part of most refurbishment and new build projects: They also require significant periods of time to be allocated in the construction program to install and commission. Any changes to these systems that reduce the time taken to install and commission can only help the construction process. With even a simple building requiring six or more systems, this would normally require cabling to be installed for the six non-integrated systems, requiring significant support and containment systems.

In addition, significant time has to be allocated to the commissioning of these, often requiring a great deal of co-ordination by the engineering contractors to ensure the specialist contractors commissioning do not clash with the commissioning of other control and monitoring systems.

With a fully integrated system, the cabling installation is significantly reduced (see capital costs benefits), because one communications cable is used for all systems.

The time taken to program the system is also reduced, though even with traditional systems this could be reduced from the current times. The reductions with integrated systems are greater because there are fewer companies involved. Because they are all working on the same communications system any coordination issues between the companies are easily resolved. The tools used by the integrators are also standardised for integrated systems often using MS Visio, and smart controls visual control (see Figure 22 and 23). These commercially available programming tools are used in many industries (these are rarely used to program traditional systems as the manufacturers of these use there own home grown programming tools [see figure 21], for which finding integrators familiar with there use is more difficult).

```
00271 IF("S.KIT.EXT.FAN.FIRE.OVERRIDE" .EQ. OFF .AND.
"S.KIT.SUP.FAN.FIRE.OVERRIDE" .EQ. OFF) THEN "S.KIT.AHU.REMOTE.FIRE.OR" = OFF
00275 GOTO 560
00280 C --PLANT IN FIRE SUPPLY FAN RUN
00290 IF("S.KIT.AHU.PLANT.CONTROL" .EQ. 4) THEN GOTO 300 ELSE GOTO 350
00300 OFF("S.KIT.AHU.EXT.FAN")
00310
      ON("S.KIT.AHU.DAMPER.C","S.KIT.AHU.SUP.FAN","S.KIT.AHU.REMOTE.ON.LAMP","S.
KIT.AHU.REMOTE.FIRE.OR")
00320 SET(100.0,"S.KIT.AHU.SUP.FAN.SPEED")
00330
      SET(0.0,"S.KIT.AHU.EXT.FAN.SPEED","S.KIT.AHU.RR.PUMP.SPEED","S.KIT.AHU.FRO
ST.VAL")
00335 GOTO 560
00340 C --PLANT IN FIRE EXTRACT FAN RUN
00350 IF("S.KIT.AHU.PLANT.CONTROL" .EQ. 3) THEN GOTO 360 ELSE GOTO 410
00360 OFF("S.KIT.AHU.SUP.FAN")
00370
      ON("S.KIT.AHU.DAMPER.C","S.KIT.AHU.EXT.FAN","S.KIT.AHU.REMOTE.ON.LAMP","S.
KIT.AHU.REMOTE.FIRE.OR")
00380 SET(100.0,"S.KIT.AHU.EXT.FAN.SPEED")
00390
      SET(0.0,"S.KIT.AHU.SUP.FAN.SPEED","S.KIT.AHU.RR.PUMP.SPEED","S.KIT.AHU.FRO
ST.VAL")
00395 GOTO 560
00400 C --PLANT IN FROST
00410 IF("S.KIT.AHU.PLANT.CONTROL" .EQ. 2) THEN GOTO 420 ELSE GOTO 460
00420
      OFF("S.KIT.AHU.DAMPER.C","S.KIT.AHU.SUP.FAN","S.KIT.AHU.EXT.FAN","S.KIT.AH
U.REMOTE.ON.LAMP")
00430
      SET(0.0,"S.KIT.AHU.SUP.FAN.SPEED","S.KIT.AHU.EXT.FAN.SPEED","S.KIT.AHU.FRO
ST.VAL")
00440 SET(100.0,"S.KIT.AHU.RR.PUMP.SPEED","S.KIT.AHU.FROST.VAL")
00445 GOTO 560
00450 C --PLANT RUN
00460 IF("S.KIT.AHU.PLANT.CONTROL" .EQ. 1) THEN GOTO 470 ELSE GOTO 790
00470 ON("S.KIT.AHU.DAMPER.C","S.KIT.AHU.REMOTE.ON.LAMP")
00471 OFF("S.KIT.AHU.REMOTE.OFF.LAMP")
00480 "S.KIT.AHU.EXT.FAN" = "S.KIT.AHU.DAMPER"
00490 "S.KIT.AHU.SUP.FAN" = "S.KIT.AHU.DAMPER"
00491 IF("S.KIT.AHU.SUP.FAN" .EQ. OFF) THEN "S.KIT.AHU.SUP.FAN.PRES.TIMER" = 0
00492 IF("S.KIT.AHU.SUP.FAN" .EQ. ON .AND. "S.KIT.AHU.SUP.FAN.PRESSURE" GE.
"S.KIT.AHU.SUP.FAN.PRES.SP") THEN "S.KIT.AHU.SUP.FAN.PRES.TIMER" =
"S.KIT.AHU.SUP.FAN.PRES.TIME.SP"
00493 SAMPLE(1) IF("S.KIT.AHU.SUP.FAN" .EQ. ON .AND.
"S.KIT.AHU.SUP.FAN.PRESSURE" .LE. "S.KIT.AHU.SUP.FAN.PRES.SP") THEN
"S.KIT.AHU.SUP.FAN.PRES.TIMER" = "S.KIT.AHU.SUP.FAN.PRES.TIMER" - 1
```

Figure 18: A still common method of programming for single vendor BMS.

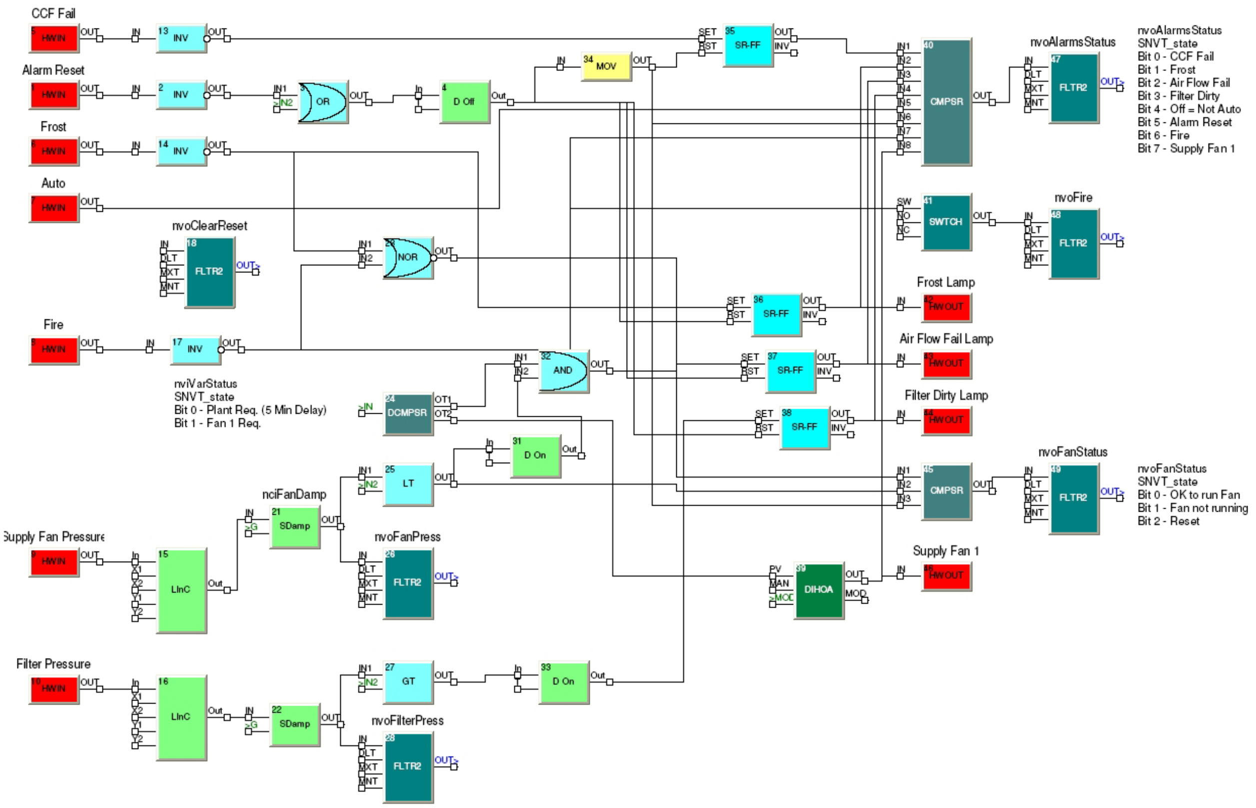


Figure 19: Change-over unit using visual control program for LonWorks illustrating clarity and simplicity of visual programming techniques.

On site, commissioning of “fully-integrated” systems tends to be much quicker because there is much less co-ordination required between contractors. Additionally the programs written off-site are more complete. During the on site commissioning period the main task is typically witness testing and demonstrating the operation of the system. Whilst there is no single reason for integrated systems, to be better than traditional systems there are a number of factors as listed below:-

- better programming tools (see Figure 21);
- more able integrators;
- integration companies tend to be more customer focused (competition);
- fewer companies involved in the on site and commissioning process.

The above not only results in program timing savings, typically two weeks on a 40 week contract, but also results in a better commissioned system (subjective) at a time in the construction program when slippage is least acceptable.

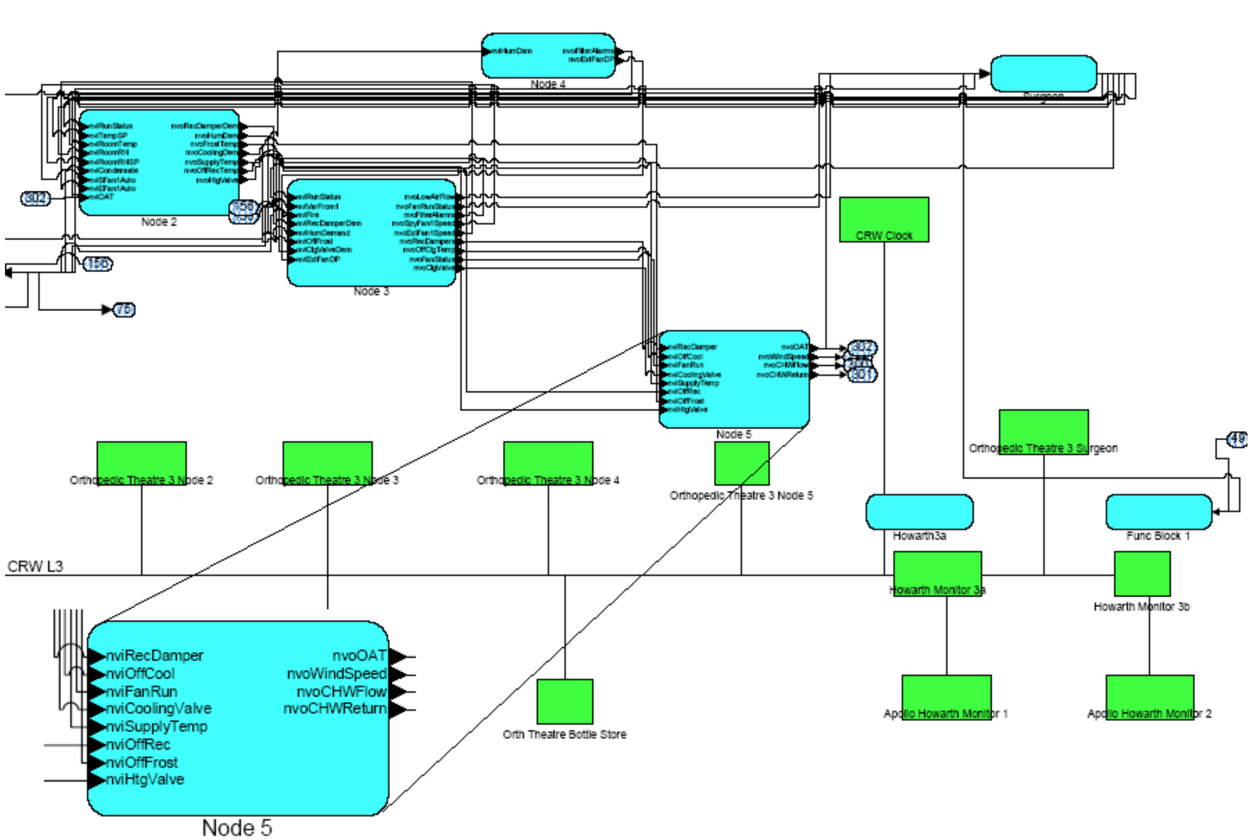


Figure 20: Network diagram showing points connected to controllers as written in visual control, for variable speed air conditioning ventilation system for an operating theatre.

4.12 Environmental benefits

In addition to the environmental benefits of reduced cabling and components needed for a system to perform a specified task as previously discussed, there are also benefits arising from additional energy savings from a better commissioned and maintained system (self-diagnosing).

Whilst no formal evaluation has taken place, with the large capital savings from “fully-integrated” systems, the reduction in materials (normally highly engineered) must be significant. These continue through the buildings operational life as the sensors and general components used tend to be of a higher quality and are fewer in number. Reduced replacements are also needed during the life of the building as a result.

With any products or systems, when improvements in manufacturing, design, cost, etc. are made they tend to become more commonly used. This is as true with integrated systems as PCs and mobile phones in the past.

As with PCs, backward compatibility has allowed the market to expand and utilise common interfaces such as USB ports. “Open” systems are backward compatible therefore with additions, changes and refurbishments in the future, only the components that need changing will be changed.

Appendix 1

A different approach to Medical Gas Alarm Systems

A) Objective

In this Appendix I aim to illustrate use of appropriate software, innovation, fitness for purpose, analysis, practical problems, technical knowledge, relevant equipment (in this case relevant software) and application of engineering practices (in terms of design, commissioning and maintenance).

B) Advanced Medical Gas Alarm Systems

Challenge:-

To collectively improve reliability of gas flow to the patient and therefore patient safety and gas availability.

To use reliability centred maintenance techniques making use of known system and sensor characteristics:-

- To improve the effectiveness of capital expenditure on medical gas delivery systems

- To improve management of the piped medical gas installation at XXXXX Hospital, by improving system operation

- To improve availability of the systems and reduce “near miss” incidents including
    - Leak and incorrect cylinder change procedure alarms
    - Heavy usage plant alarm
    - Heavy gas usage warning alarm
    - System self monitoring techniques

B1) Reducing Capital Spend

The value of the installation at XXXXX General Hospital is in the region of £1.5M comprising many plants and pipe-work systems.

Over the years I have observed many design related problems including:-

- Installation of unnecessary plant;
- Install unnecessary Pipework;
- Undersized emergency manifolds (see later section for discussions on this subject).

Designers have tended to specify either larger plant and or pipe-work installations, the designers sighting design flow rates from the national design standard for medical gas installations HTM 2022 [5] as the reason for the new pipe installations and plant. In the case of plant replacements even site based evidence of under utilised plant [6] (from hours run clocks) historically has not been accepted as evidence for sufficient existing plant capacity.

Note: Designers tend to assume that with a plant running for an average of 5 minutes in the hour that the peak consumption is concentrated around one hour a day, in practice this is not true, but without that proof the designer rightly takes the more cautious route.

Figure 21: Slide taken during a working day the largest plant CRW Basement had not run in the last hour!!!

For designers to assess if an existing medical gas system is suitable for extension, there are Four questions that always need answering, for which standards and the systems including alarms offer little or no help. These are:-

- Will the pipeline installation take the new load?
- Is there sufficient cylinder storage capacity?
- Do the medical air and vacuum compressors have sufficient capacity?
- What's a VIE?

In this section of the report I will outline how monitoring systems do help answer these questions.

[5] HTM 2022 medical gas pipeline systems Design, installation, validation and Verification NHS Estates 1997
[6] Questioning oxygen flow rate guidance Stuart Ward, P31 HEJ IHEEM August 2004

B2) Improve Availability of Systems

As medical gas installations are life support systems they are always provided with emergency back up plant, or manifolds of cylinders. On numerous occasions these have been found nearly empty, or just above the alarm level. In practice, in an emergency the remaining quantity of gas would be exhausted very quickly leading to a medical emergency.

Other systems with similar problems include medical air and vacuum plant, where compressors are found to be running continuously, e g caused by medical gas regulators being left open (more noticeable on smaller systems).

B3) To Reduce "Near Misses'

Exampled by leaks on manifolds or only one cylinder being changed on a large manifold have lead to the virtual exhaustion of the gas supply system.

B4) Existing medical gas and vacuum installations

Whilst there is a well developed standard for medical gas alarms and installations,[1,7,4] HTM 2022 is understandably pessimistic about gas usage and does not incorporate the monitoring techniques available from more advanced monitoring systems (the alarm system utilises only pressure switches) to bring advanced warning of developing plant faults and incorrect procedures or the feed back information to allow the design information to be updated.

The standard was initially developed and published in 1972 as HTM 22, and came about after a number of problems were experienced abroad and in the UK:-

- Supply failures
- Wrong gas administered to patient
- Poor gas quality etc.

With respect to this report the standards[1,4] specify the:-

- Operating pressures of the various gas and vacuum delivery systems
- Typical design gas flow rates
- Gas alarm systems.

1. Operating Pressures

Regarding system operating pressures these are allowed to vary between predetermined limits to allow the practical installation of the delivery systems. These limits are set to prevent the quantity of gas delivered to the patient from varying too widely (regulation at point of use is by needle valve). The object of the Facilities Manager is to have installed a medical gas system that just meets these delivery pressure requirements with sufficient extra capacity installed as required.

[7] NHS Model Engineering Specification C11 Medical Gases 1996

2. Flow Rates

These were developed following investigations at a number of hospitals prior to the publication of the standard, and have lead to significant over sizing of plant and pipeline systems within the UK (and other countries)[2]. The Facilities Manager's objectives are similar to the "operating pressures" above.

3. Gas Alarms

These have remained largely unchanged, e .g. a light is illuminated and audible alarm sounds when a pressure switch operates because the pressure has fallen below or raised above a permitted level. In the USA medical gas alarm systems operate in a similar manner with some "combination" systems displaying the system pressure on the "plant" alarm panels.

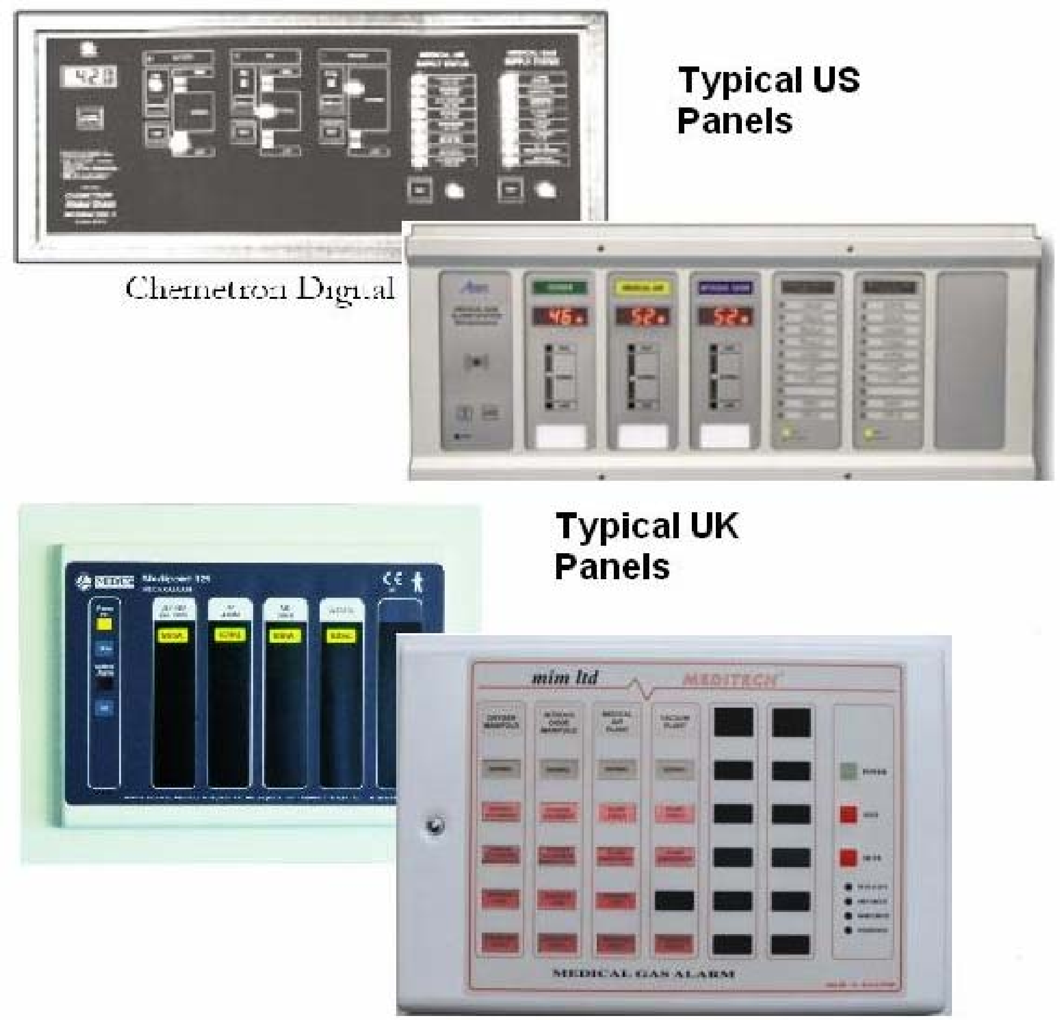


Figure 22: Typical Medical Gas Plant alarm Panels from US and UK.

In conclusion the base operating requirements are well founded, but the installations would benefit from value engineering and would benefit operationally from condition based monitoring systems to improve reliability and availability[8] of systems.

When the existing medical gas alarm system at XXXXX General Hospital needed replacing I took the opportunity to address the issues raised above.

The new medical gas monitoring system (completed July 2004) comprises:-

- A traditional medical gas alarm system
- Pressure sensors located at the end of each system's index run
- Pressure sensors located on each manifold
- Digital inputs from each compressor motor
- A screen based copy of the medical gas alarm panels, plus graphic report pages for the additional monitoring systems that could be viewed on any PC in the Trust.

5. Index run pressure sensors

These perform several useful functions, and I have set these to two stages of alarm both high and low (vacuum high only), to give advanced warning of:-

A low pressure (high pressure for vacuum) alarm when the system is operating at near capacity
Or

A faulty pressure reducing valve or valve set to the wrong pressure

Or

A faulty vacuum plant control (high pressure)

These alarms give useful automated feed back on the health of the medical gas systems. The first stage gives a warning intended to allow time for management to start planning to resolve the implications of the alarm.

6. Calculating Spare System Capacity

There are two ways the information from these sensors can be used to estimate spare capacity on the system, these are as follows:-

[8] Reliability-Centred Approach Evaluated William R Steele IHEEM February 2005

6.1. Estimation of capacity using index EOL pressure logs

System curves are used in fluid flow systems such as ventilation and wet heating systems to assist with fan/pump re-commissioning following system extension to estimate the new speed of the fan/impeller. This can equally be applied to medical gas pipeline installations, to ascertain the remaining spare capacity in the system as follows:-

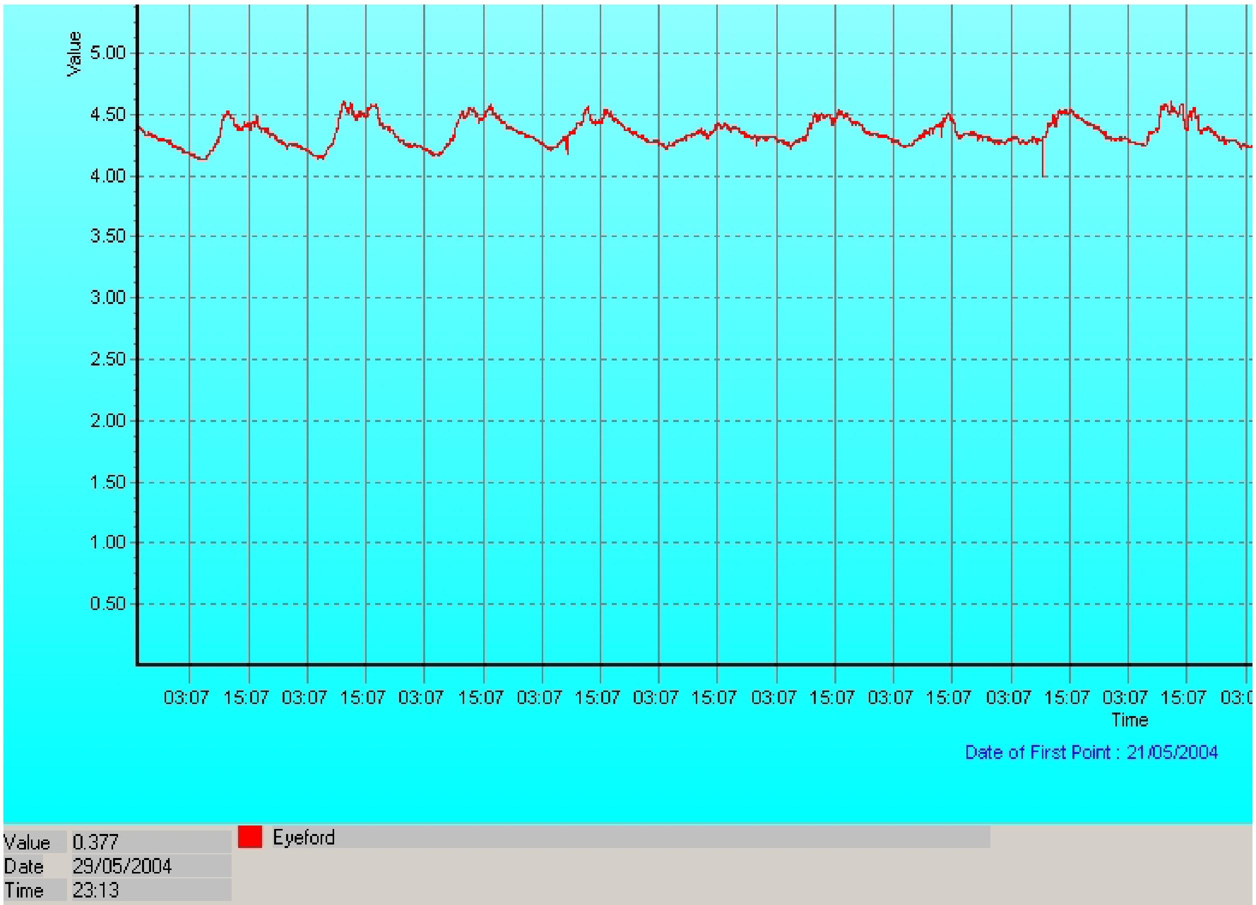


Figure 23: Sample pressure log for EOL pressure sensor on index run of Oxygen pipeline.

Data

Permitted supply pressure tolerance at ward or departments[1 Table 19]	±20%
Maximum pressure tolerance at ward or departments	4.92 bar
Minimum pressure tolerance at ward or departments $(Dep_{\min})$	3.28 bar
Actual line pressure at pressure reducing valve oxygen (adjusted for accuracy) (P_o)	4.8 bar
Minimum line pressure at EOL (end of line) from log (index run) $(EOL_{\min})$	4.25 bar
Maximum line pressure at EOL (information only)	4.6 bar
Monitoring Sensor overall accuracy (PS)	±0.01 bar
Alarm Pressure Switch operating differential (DP)	0.1 bar
Note system nominal design operating pressure is	4.0 bar

To find the working pressures available after sensor accuracies are taken into account

Minimum pressure at index run (P_{i2})

$$Dep_{\min} + DP = P_{i2}$$
$$3.28 + 0.1 = 3.38 bar$$

Note: In the current edition of HTM 2022 the minimum pressure at the face of the terminal is required to be 3.55bar this has been used in this calculation and not the area alarm low pressure setting. Note this pressure is at variance with the low pressure alarm $(Dep_{\min})$

Minimum line pressure at EOL (P_{i1})

$$EOL_{\min} - PS = P_{i1}$$
$$4.25 - 0.1 = 4.24 bar$$

The system curve formula may be adapted to give the available capacity expressed as a ratio or percentage

$$R = k(Q)^2$$

Because at this point the system has not been altered the system constant will remain unchanged and cancelled out. The formula can be developed to give the revised value of R if the volume flow of the system is increased

$$\frac{R_2}{R_1} = \frac{k}{k}\left(\frac{Q_2}{Q_1}\right)^2$$
$$\frac{R_2}{R_1} = \left(\frac{Q_2}{Q_1}\right)^2$$

R in this case is the differential pressure between the supply pressure and the end of index run pressure.

The formula can be modified to:-

$$\frac{R_2}{R_1} = \left(\frac{Q_2}{Q_1}\right)^2$$
$$\frac{P_{o2} - P_{i2}}{P_{o1} - P_{i1}} = \left(\frac{Q_2}{Q_1}\right)^2$$

As with this method of calculation the initial volume flow rate is not known, Q_2 can only be represented as a ratio of Q_1

$$\frac{P_{o2} - P_{i2}}{P_{o1} - P_{i1}} = \left(\frac{Q_2}{Q_1}\right)^2$$

$$\sqrt{\frac{P_{o2} - P_{i2}}{P_{o1} - P_{i1}}} = \frac{Q_2}{Q_1}$$

To substitute percentage capacity available $(cap\%)$ the volume flow aspects are modified as follows:-

$$\sqrt{\frac{P_{o2} - P_{i2}}{P_{o1} - P_{i1}}} = \frac{Q_2}{Q_1}$$

$$\sqrt{\frac{P_{o2} - P_{i2}}{P_{o1} - P_{i1}}} = Q_{Ratio}$$

$$and$$

$$(Q_{Ratio} - 1) \bullet 100 = cap\%$$

Substituting data gives

$$\sqrt{\frac{P_{o2} - P_{i2}}{P_{o1} - P_{i1}}} = Q_{Ratio}$$

$$\sqrt{\frac{4.8 - 3.55}{4.8 - 4.24}} = 1.49$$

$$and$$

$$(Q_{Ratio} - 1) \bullet 100 = cap\%$$

$$(1.49 - 1) \bullet 100 = 49\%$$

This figure is of direct use when evaluating spare system capacity to allow for future increase in consumption over the site. If an additional load is proposed e.g. a ward block, from this capacity calculation it may be safe to conclude the system has sufficient capacity for the new load without further calculation, dependant of the new loads point of connection.

To determine if an existing system has sufficient capacity for a planned extension is difficult, there are rarely if ever devices e g meters recording flow or pressure. The designer has little to go on. The traditional approach is to load up the system schematic with the theoretical loads based on the diversified flow rates given in the various sections of HTM 2022:1997. These are perceived by the industry[2] as a whole as being over pessimistic leading to over design, so these flow diversities, when applied to the existing system lead the designer to think there is little scope for accommodating additional loads.

Developing the calculations above can give a much better approximation as to the effect on the system as a whole of the addition of say a new ward block (C). The following is a sample calculation based on a much simplified system.

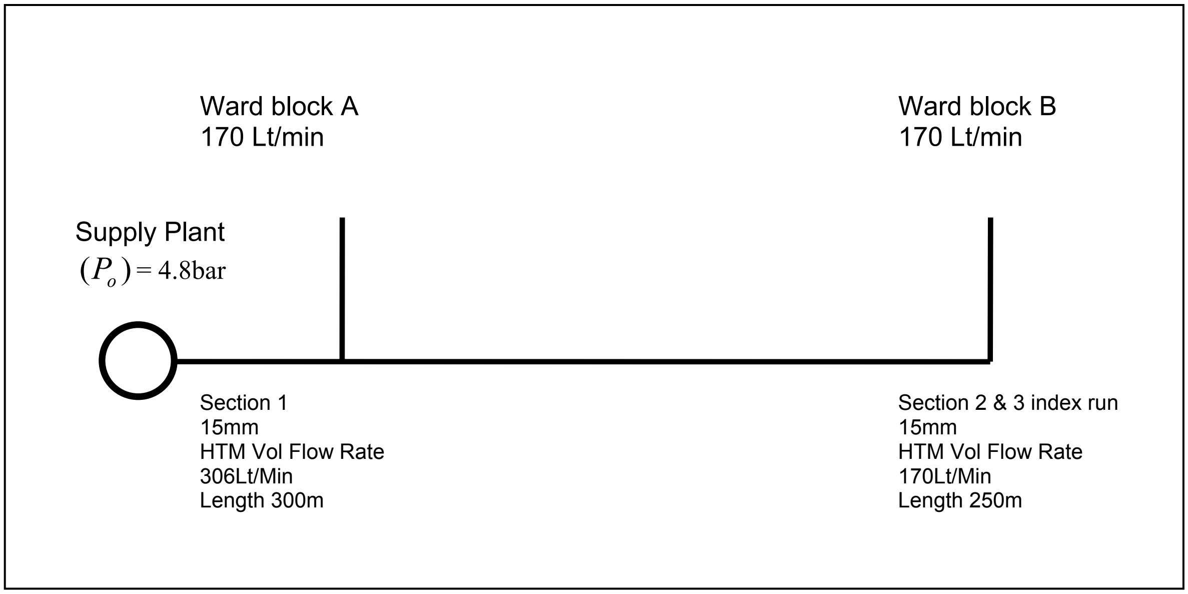


Figure 24: Existing pipeline schematic.

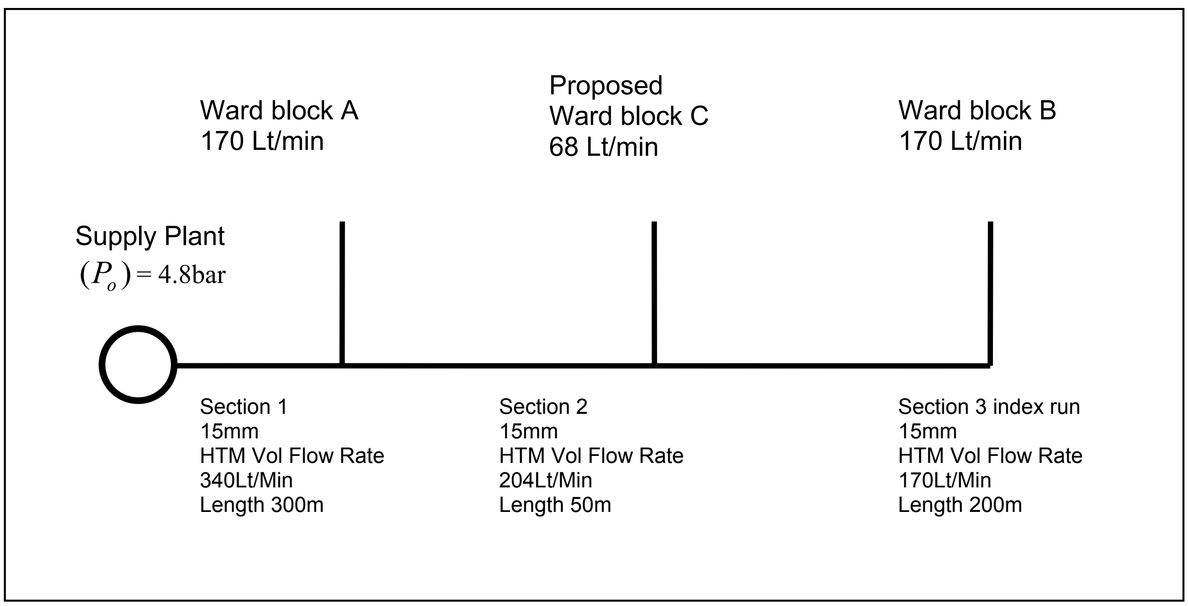


Figure 25: Proposed pipeline schematic with additional ward block.

Based on HTM 2022 table 6[1] the diversified flows along each pipe are indicated in figure 4 and 5 above.

In this example the actual peak volume flow rate for the existing system is not known, but the resultant pressure drop at peak flow is. Based on the diversified flows of the "proposed" system (Figure 5) and those of the existing (Figure 4), the ratio between the proposed and existing can be calculated. The ratio of design diversities in Figs.4 and 5 indicates the peak flow rate would increase by 11% (340Lt/min/306Lt/min), and to this should be added a contingency dependent on where the connection is to be made relative to the point of origin. If the calculated spare capacity were in the region of 30% the risk should be minimal, because this is based on the peak actual oxygen requirements from the wards. Finally the pipeline resistances can be calculated to check the pipe installation, can pass the increased flow to the point of connection. A worked example based on Figures 4 and 5 is outlined in Tables 1 and 2. Tables 3 and 4 give comparisons with HTM 2022 diversified flows.

The designer has a much improved basis from these index run pressure logs for making design decisions. Without this information, there is no physical basis for decision making, unless the area alarms have warned of low pressure in the past. Pressure switches give no idea of how close the system is to failing, however the common practice of supplies to new wards being run from the plant and not the pipeline that can take the additional flow.

In practice an additional load on the system will be connected to a single point of the pipe-work installation. One of the disadvantages of pressure switch alarms is that the operator of the system has no idea what the actual system pressure is downstream of the supply pressure gauge. If there is no alarm registered, the only conclusion that can be drawn is that the line pressure is above the minimum and below the maximum permitted. The advantage with pressure sensors is they display the actual pressure and if these are logged at one minute intervals, the quantity of pressure data makes an informed decision very much easier.

The minimum line pressure recorded in the log indicates the time of maximum flow on the system, as outlined in the calculations above. Note, in theory if all the outlets at the end of the index run were open and few at the origin of the pipeline, it is possible for this to record a low line pressure at the end of the index run, because of the high flow through the relatively small pipes at the end of the system. Statistically this is not likely, however if most of the load is near to the origin of the system, this will have a lesser effect on the end of line pressure, resulting in a slightly higher pressure at the end of line pressure sensor than the actual load would suggest. For these reasons it is sensible to allow a contingency to cover this eventuality.

Outline Calculation

Table 1:

Hypothetical medical gas pipe line capacity calculation					
	units				Total
Section		1	2	3	
Pipe Size	mm	15	15	15	
Length (TEL)	m	300	50	200	550
Existing Installation					
HTM 2022 diversified flow rate	Lt/m	306	170	170	
Current average ΔP/m	Pa/m	102	102	102	
Operational Maximum flow rate from Appendix J HTM 2022	Lt/m	170	170	170	
Proposed Installation					
New HTM 2022 diversified flow rate	Lt/m	340	204	170	
Existing HTM 2022 diversified flow rate	Lt/m	306	170	170	
Estimated gas flow rate increase	Lt/m	34	34	0	
Estimated new flow rate	Lt/m	204	204	170	
Estimated new average ΔP/m from Appendix J HTM 2022	Pa/m	155	155	102	
Estimated new pressure loss	bar	0.47	0.08	0.20	0.75

Table 2:

Base data and summary for Table 1			
Existing Po	bar	4.8	
Existing EOLmin	bar	**4.24**	
Estimated new EOLmin	bar		**4.05**
Current average ΔP	bar	0.56	
Minimum pressure at Terminal	bar	3.55	

In table 1 it is likely that there will be greater flow in section 1 than 170Lt/min and less in sections 2 and 3. At least likely inconsistencies are easier to see and can be focused on with this method. With section 1, an increased estimate for the existing flow could be made (and an equivalent reduction in sections 2 and 3). These in practice will approximately balance out. As can be seen from the estimated new EOL_{min} 4.05 bar, there is still plenty of pressure available.

Tables 3 and 4 calculate the new line pressure at the end of the index run based on the calculation method recommended in HTM 2022. This results in a new end of line pressure of 3.32 bar, the new end of line pressure from this calculation would be below the minimum pressure permitted at the terminal of 3.55 bar. Whilst this method is safe the client would be expending additional capital for new Pipework etc. that is not necessary.

Table 3:

Traditional HTM calculation for Hypothetical medical gas pipe line installation					
HTM calculations					Total
Existing	Lt/m	306	170	170	
Current average ΔP/m from Appendix J HTM 2022	Pa/m	300	100	100	
Estimated existing pressure loss	bar	0.9	0.05	0.2	1.15
Proposed Installation					
New HTM 2022 diversified flow rate	Lt/m	340	204	170	
Estimated new average ΔP/m from Appendix J HTM 2022	Pa/m	400	150	102	
Estimated new pressure loss	bar	1.2	0.08	0.20	1.48

Table 4:

Base data and summary for Table 3			
Existing Po	bar	4.8	
Calculated existing EOLmin	bar	**3.65**	
Estimated new EOLmin	bar		**3.32**
Minimum pressure at Terminal	bar	3.55	

General

From the index pressure sensor data, other information about the systems performance can be derived, e.g. the variation of flow over time expressed as a percentage of the highest logged pressure or the mathematical average, the results being expressed as a percentage about or above the datum selected.

Note:-

Medical gas consumptions (particularly oxygen) vary significantly typically, heavy consumptions being observed around January. Entonox consumption also varies widely, this being linked to gas assisted births.

6.2 Estimation of Capacity using Index EOL Pressure Logs and usage Logs

An approximation of available system capacity can be gained by the pressure change observed in the index sensor, the supply pressure at the origin of the supply system (physical pressure gauge), and the quantity of gas used. The method of logging the gas quantity consumed is discussed later.

For useful information to be gained, during the sample period neither the pressure sensor at the origin of the system or the index run pressure sensor should be adjusted. Also there should be no gaps in the usage log.

The resultant capacity information can be used as a guide to indicate the general extra capacity available for additional gas usage. The figure is only true if the increase is applied to all points of gas usage in the system at the same rate, this in itself is useful e g oxygen usage is currently increasing at 4% to 6% per year. This can be projected forward to help generate an action plan, to modify the system, before problems arise.

As with estimating system capacity using index EOL pressure logs above, the same formula can be used to form the basis for this calculation technique.

$$\sqrt{\frac{P_{o2}-P_{i2}}{P_{o1}-P_{i1}}}=\frac{Q_2}{Q_1}$$

In this case the EOL index pressure sensor log is viewed and the time is recorded with the value of the lowest pressure. The corresponding manifold pressure log can be retrieved, and the pressure differential decrease calculated. From this the peak flow can be calculated.

(Q_1) Can now be inserted in to the equation to give the value for (Q_2)

Note: It would also be possible to use the manifold pressure logs to calculate the maximum pressure loss, but this is more complex to identify with readily available software. It is easier to search for a minimum end of line pressure in a spread sheet.

As can be seen above these techniques give a much better approximation to better enable effective management of medical gas pipeline systems.

In conclusion information gained in this way can be used to provide proof that there is sufficient capacity to allow extensions of the system, leading to an overall capital spend reduction, often far in excess of the capital cost to install the monitoring system (£30,000). Precautions should still be taken when interpreting the information from the system. The installation of these additional sensors has a further advantage in that when the extension is completed, it provides a 1st and 2nd stage monitoring system to prove pressure drops are within the specified requirements (also providing feed back to refine the design process).

6.3 Active Monitoring of Emergency Medical Gas Manifolds

Figure 26: Entonox emergency manifold.

Emergency manifolds provide a supply of medical gas in the event of a failure of the normal supply. Rarely used, the cylinders often spend long periods of time (months) at pressures near to the alarm settings for the medical gas alarm system; due to small amounts leaking through the pressure reducing valve into the main supply pipeline. As a result, the gas available in an emergency is greatly reduced, this may only be sufficient for an hour. In practice there is often not the staff on site to be able to resolve the supply issue within the time available e.g. overnight. This coupled with the comparative lack of space for larger reserve manifolds.

A low cost alternative was to fit pressure sensors to the reserve bank and monitor the pressure of the cylinders. This trebles the emergency gas available (with the second cylinder also on-line).

The example below is intended to illustrate the inadequacy of an existing emergency manifold, and quantify the benefit of the installation of a pressure sensor in the emergency manifold

<u>Data</u>

Existing plant N_2O/O_2 (Entonox) comprising 2 x 6 cylinder run and standby manifolds plus 2 cylinder emergency manifolds

nominal full cylinder pressure (oxygen) (p_1)	137barg or 138bar$_{abs}$
cylinder pressure will be below 63% for 25% of time	86barg or 87bar$_{abs}$
50% cylinder pressure	68.5barg or 69.5bar$_{abs}$
10% cylinder pressure	13.7barg or 14.7bar$_{abs}$
usable cylinder pressure	7barg or 8bar$_{abs}$
estimate based on nominal supply pressure	4.2barg or 5.2bar$_{abs}$
diversified flow rate for system from HTM 2022[1] (Q_d)	355Lt
G size cylinder capacity at STP	5000Lt

6.4 Manifold Operation

In normal operation the duty bank supplies gas until the bank is exhausted, the standby bank then takes over and an alarm is generated to "change cylinders".

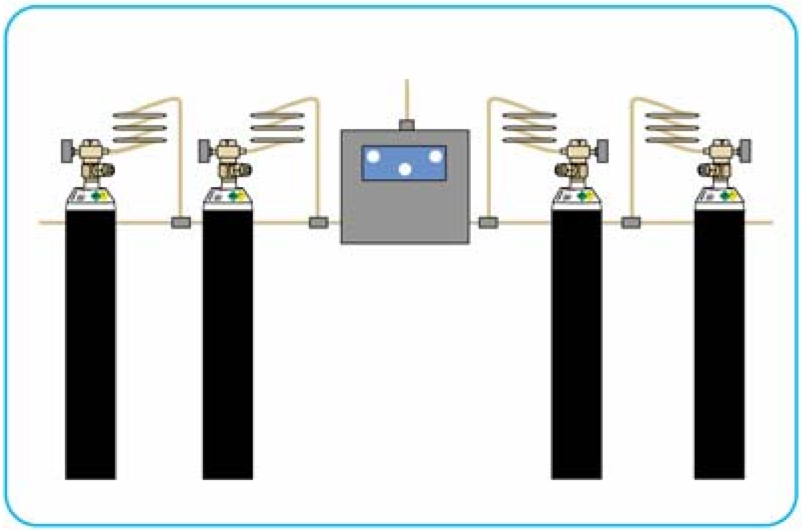


Figure 27: Diagrammatic layout of a typical automatic change over manifold.

Only if the cylinders are not replenished would this develop on to an abnormal situation. The next alarm "change cylinders immediately" would be the start of an emergency situation. This alarm is generated when only 10% of the nominal pressure remains in the now duty bank, the other bank still being empty. It is quite possible for the emergency bank to be just above the 50% pressure alarm point (the pressure at which the emergency bank generates its own alarm). As the pressure is continuously lost through the PRV this manifold will be at 86bar (63%) or below for 25% of the time.

6.5 how long might the emergency supply last?

Quantity of unusable gas remaining in each cylinder at 7bar (8bar$_{abs}$)

To illustrate the relative vulnerability of the medical gas supply installation the following calculation assesses the available time following the initiation of the "change cylinders immediately" alarm before the supply of gas is lost.

$$\frac{\text{Full capacity } Cap_1}{\text{Full cylinder pressure } p_1} = \frac{\text{diminished capacity } Cap_2}{\text{diminished cylinder pressure } p_2}$$

$$\frac{Cap_1}{P_1} = \frac{Cap_2}{p_2}$$

Making Cap_2 the subject

$$Cap_2 = \frac{Cap_1 p_2}{P_1}$$
$$Cap_2 = \frac{5000 \bullet 8}{138}$$
$$Cap_2 = 290Lt$$
$$or$$
$$Cap_{8barabs} = 290Lt$$

Usable gas for a cylinder at 10% nominal pressure $(Cap_{14.7barabs})$

$$Cap_2 = \frac{Cap_1 p_2}{P_1}$$
$$Cap_2 = \frac{5000 \bullet 14.7}{138}$$
$$Cap_2 = 532Lt$$
$$or$$
$$Cap_{14.7barabs} = 532 - 290$$
$$Cap_{14.7barabs} = 242Lt$$

Usable gas for a cylinder at 63% nominal pressure $(Cap_{87barabs})$

$$Cap_2 = \frac{Cap_1 p_2}{P_1}$$
$$Cap_2 = \frac{5000 \bullet 87}{138}$$
$$Cap_2 = 3152Lt$$
$$or$$
$$Cap_{87barabs} = 3152 - 290$$
$$Cap_{87barabs} = 2862Lt$$

Gas available for use as the “change cylinders immediately” alarm is initiated

6No. cylinders at 10% $(Duty)$

$$Duty = Cap_{14.7barabs} \bullet Cylinders$$
$$Duty = 242 \times 6$$
$$Duty = 1452Lt$$

1No. cylinder at say 63% *($Em_{87barabs}$)*

$$
\begin{aligned}
Em &= Cap_{14.7barabs} \bullet Cylinders \\
Em &= 2862 \times 1 \\
Em &= 2862Lt
\end{aligned}
$$

Quantity of gas available before emergency supply exhausted *(Em_{av})*

$$
\begin{aligned}
Duty + Em &= Em_{av} \\
1452 + 2862 &= 4314Lt
\end{aligned}
$$

Time to react before supply exhausted *(t)*

$$
\begin{aligned}
t &= \frac{Em_{av}}{Q_d} \\
t &= \frac{4314}{355} \\
t &= 12\min
\end{aligned}
$$

Assuming that the “change cylinders immediately” alarm occurs and this coincides with the peak diversified flow, the emergency supply may last for only 12 minutes. Whilst it would not be expected for this flow rate to last for hours, 12 minutes could easily be required.

With the second emergency cylinder brought on line and the alarm level set to 80% this figure improves to 25 minutes: by no means satisfactory, but much better than the previous state of affairs. These problems were highlighted by the pressure graphs showing pictorially the decline of the emergency reserve over time

The effect of this change in operation is that the number of cylinders used over time rises significantly, however, this is still a very small cost as the number of cylinders used on these emergency manifolds is very small compared to the main usage.

The current recommendations[1] concerning the sizing/provision of emergency manifolds recommend

“Emergency reserve supplies for manifold systems”

“5.32 A two-cylinder emergency reserve supply would normally be considered adequate for a cylinder manifold supply system.” Clause 5.24 suggests “a 4 hour reserve”, clearly inconsistent and a good case for revision of the standard.

Elsewhere in the document reference is made to the “operational policy” for operating the medical gas delivery system. This would benefit from an agreed reaction time for attending to plant alarms.

It should be noted that the guidance only contains information on peak diversified flow rates, not prolonged consumption rates that would be necessary to assist with the correct sizing of emergency manifolds.

The pressure sensor provides additional facilities to improve reliability and availability, these are:-

- Monitor pressure to both cylinders and change at 80%
- Monitor pressure to detect a leak or a leaking Pressure Reduction Valve
- The reserve of gas is observable at all times
- The gas pressure is logged for record purposes (good controls assurance)
- The pressure sensor is notionally recalibrated each time the cylinders are changed (see note below).

Note: The pressure sensor cannot in this case be self tested by using say the average peak pressure of say the last four cylinder pressure changes. Whilst this would negate most of the effect of the new cylinder pressures for temperature effects on pressure between summer and winter (approximately 9% from 30 deg c to 5 deg c). Any sensor drift will also be included in this average, so it would not be sensible to recalibrate the pressure sensor each time the cylinders are change. Instead the sensor could calibrate itself to say ±10% of the nominal full cylinder pressure. As yet this has not been set up.

6.6 Pressure changes in cylinders due to temperature change

To demonstrate the variance of pressure in medical gas cylinders under differing temperatures e.g. summer/winter

Data

Summer temperature in manifold room maximum (T_2)	30°C or 303°K
Winter temperature in manifold room minimum (T_1)	5°C or 278°K
Nominal full cylinder pressure (oxygen) (p_1)	137barg or 138bar$_{abs}$

From a combination of Charles's Law and Boyle's Law

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2}$$

As cylinder volume is constant $v_1 = v_2$

$$p_2 = \frac{p_1 T_2}{T_1} \bullet \frac{v_1}{v_2}$$

$$p_2 = \frac{p_1 T_2}{T_1}$$

$$p_2 = \frac{138 \bullet 303}{278}$$

$$p_2 = 150 bar_{abs}$$

Or about 9%

Figure 28: shows pressure decay in manifolds as gas is consumed.

Notes:-

Cyclical change in pressure is due to day/night temperature change (see later calculation).

In centre of graph note manual change of duty/standby banks.

To the right of the graph, note higher pressure cylinders connected to standby bank, Delivered cylinder pressures also vary.

6.7 Active Monitoring of Medical Gas Manifolds

Medical gas manifolds for the supply of gas in the UK comprise two banks of cylinders arranged to supply gas at reduced pressures through a mechanically operated shuttle valve. This operates when the duty bank of cylinders is exhausted.

As with installing pressure sensors on the emergency manifolds, installing one sensor per bank of cylinders provides similar information.

These sensors can be used to provide information that can be used to prove "spare capacity" or verify the satisfactory delivery pressure of the Pipework system as discussed above.

Additionally these sensors are used to reduce the occurrence of "near misses" associated with the medical gas installation by detecting:-

- When only one cylinder is changed in a bank of cylinders,
- A leak on a bank of cylinders
- The quantity of gas used over a period of time
- The rate of gas flow does not exceed the manufacturer's recommendations
- A 'self' calibration routine can be set up for manifold sensors
- The system can record (from logs) how long cylinder changes take

6.7 Incorrect cylinder change and leak detection procedure

Normally when cylinders are changed, all are replaced at the same time, however, on several occasions in the past only one has been changed leaving only one full cylinder on a bank of perhaps six,

Unfortunately, because of the design of current medical gas alarm systems the action of changing the first cylinder satisfies the audible and visual alarm. Therefore, when the bank is next "on line" the bank becomes exhausted in approximately one sixth of the normal time. This will always occur when the other bank is empty!!

For the hospital, the bank has just changed over and the cylinders need changing (a process that can take time in a busy hospital). This is often shortly followed by the "change cylinder immediately" alarm and in less than say 10 minutes the emergency cylinder will be in use. To avoid this, information from the pressure sensor can give advanced warning by monitoring the accelerated rate of pressure loss. This triggers after a delay of 5 minutes after change over. By using Charles's law to calculate the extra available gas, this gives an extra hour to resolve the situation.

Because of the seasonal nature of some gas usages, the alarm value is set by a rolling average of how long each of the last four banks was on line. This is converted in to an average rate of usage and generates an alarm when the rate of pressure drop rises by over 100%.

In a similar fashion, a leak on a bank of cylinders is detected if the pressure on the standby manifold reduces by more than 15% before changing over. The alarm threshold is based on the percentage change in pressure based on the minimum and maximum manifold temperature using a combination of Boyle's Law and Charles's Law to prove this will be less than 15% (actual 9%). See above calculation.

An alternative to prevent the wrong number of cylinders or part used cylinders from being put on to the manifold would be to install one pressure switch in each cylinder "pig tail" wired in series and interlock the "full" signal with the "Cylinder change" alarm. This solves one problem only at a similar or greater cost, than the pressure sensors.

6.9 Self Calibration of sensors

Because the manifold shuttle valve operates at a fixed pressure, when this change over occurs this is detected by the sensor and the pressure drop ceases. When a fall in pressure is observed by the other detector this confirms the change over has taken place (thus proving that there is gas being used and that gas flow has not just stopped because usage has subsided). Providing this occurs at the correct pressure (a tolerance of say 10% should be allowed) this confirms both the satisfactory operation of the shuttle valve and the pressure sensor.

The above illustrates an example of careful selection of sensors and an understanding of engineering principles used to solve a variety of capital and facilities management issues.

7.0 Conclusions

More development would be needed for the procedures to be transferred into a bespoke advanced medical gas alarm system ideally utilising an "open Protocol" to improve connectivity, reliability and cost. Whilst there are clear operational benefits these are gained by the use of fully networked systems used to convey the messages from many other systems using more advanced communication and display tools.

Finally a VIE is a Vacuum Insulated Evaporator used to store liquid oxygen!

4,800 Words

D References

[1] HTM 2022 medical gas pipeline systems Design, installation, validation and Verification NHS Estates 1997

[2] Questioning oxygen flow rate guidance Stuart Ward, MSc BA CEng FCIBSE FIHEEM MASHRAE P31 HEJ IHEEM August 2004

[3] Reliability-Centred Approach Evaluated William R Steele HEJ IHEEM February 2005

[4] NHS Model Engineering Specification C11 Medical Gases 1996