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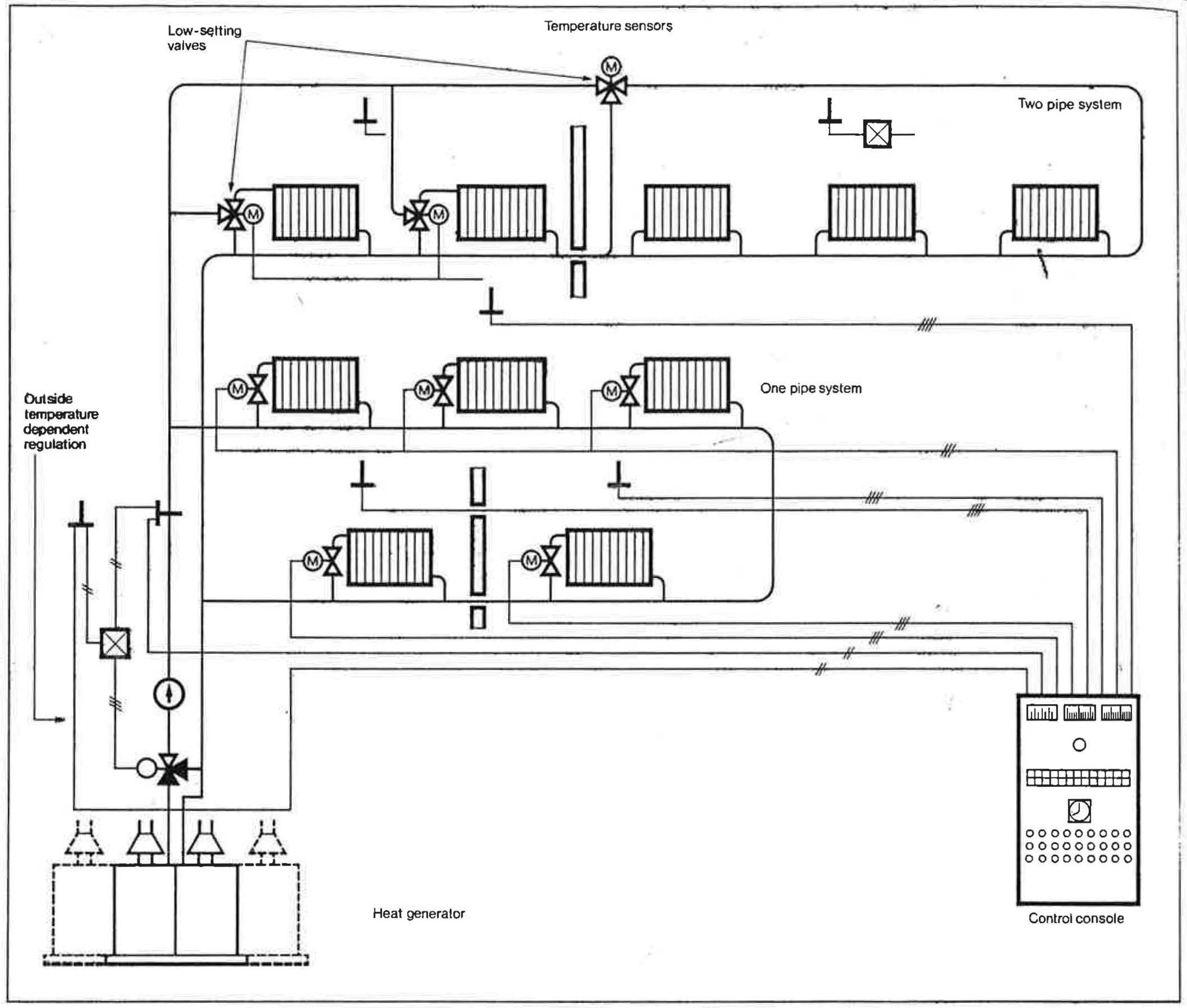


Above, figure 2: Control schematic for a warm water central heating system operating under the FER and FEL regimes.

nal port control was wedge shaped and finely engineered. Later microprocessor based electronic radiator controllers, although giving a finer control, were not suitable for the wear and tear of schools and similar institutions.

The majority of schools in Germany are mechanically ventilated to provide some relief from the high external daytime temperatures normally experienced in summer. The axial flow fan in the school I visited had a variable belt drive for speed adjustment, and electrically driven control valves to both air inlet and air exhaust ducts. This so-called elastic ventilation is known in Germany as the FEL (fernschaltbare einzelraum luftung) system.

It was in the Elly Heus Knapp School where Eugen Mayer noticed that the difference in temperature from one end to the other of a 60 m long underground corridor had a 10°C differential that led to the air in the corridor being used to cool the classrooms naturally, and thus saving on electrical power. This same practical use of free cooling and also heating in winter was adapted in every other building in Heilbronn that was controlled by the local town hall, where it was feasible.

Control facilities are shown in figure 2. A central control station has particular advantages for hospitals, schools and other service buildings. Internal temperatures in each room could be checked and manual adjustment allowed depending on the effect of the sun. The advantages can be summed up as being able to achieve exact set degree value adjustments for the temperature in a room, and not by the use of a pre-determined "design" number. There was a record of the real value of room temperature with direct access in the regulation of individual room utilisation time that allowed the adjustment of both heating and ventilating. Only one pilot control was necessary for both heating the lphw system and the control damper on the inlet air supply. Fine control was set in each individual room.

During the winter of 1978/1979, the city council discovered that more than 30% of heating energy was saved in the local schools where the system had been installed. Since that time, some 150 000 m² of Heilbronn's schools have been "elasticised", with an annual saving of DM920 000 (£270 500) with gas at DM 0·8/kWh (23·5p). Since 1978 many other buildings have been converted to the FER and FEL systems.

In place of the large control station, computer technology has entered the field to give even finer tuning. This in turn has increased the energy saving to 38-40%.

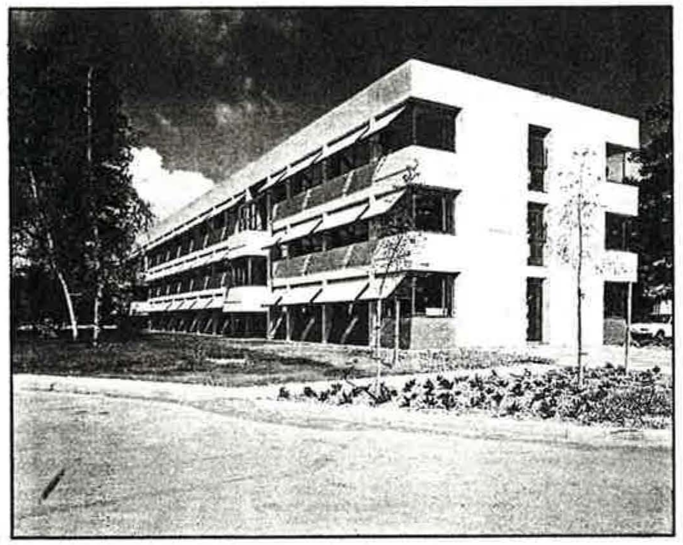
In another part of Heilbronn, building workers were putting the finishing touches to an old factory building which was being converted into a youth centre catering for all ages from toddlers to teenagers. Integral control valves designed into the radiators sent their signals back to a desk top computer. All the variables of use, and climate data had been programmed into the memory banks.

On the visual display unit, different room positions were called up. In the main sports hall, the graphic display of temperature against time showed that the bright winter sunshine was giving, for the major part of the hall, a solar gain of 12°C. The ceiling heating panels were allowed to remain open since the space was not being used, and therefore the space could be allowed to heat up naturally for the later arrival of the sports teams.

Electric heating — a viable option?

Electric heating has often come under fire on the grounds of fuel cost and environmental concerns. *R W John, S T P Willis,* and *A C Salvidge* outline the pros and cons based on experience gained at the low energy office of the BRE.

The Low Energy Office (LEO) at BRE was among the first buildings in the UK to be designed with the aim of minimising energy use[1]. Some seven years of operating experience have been used to assess the long term performance of the energy efficient features associated with the building.



Above: BRE's low energy office at Garston.

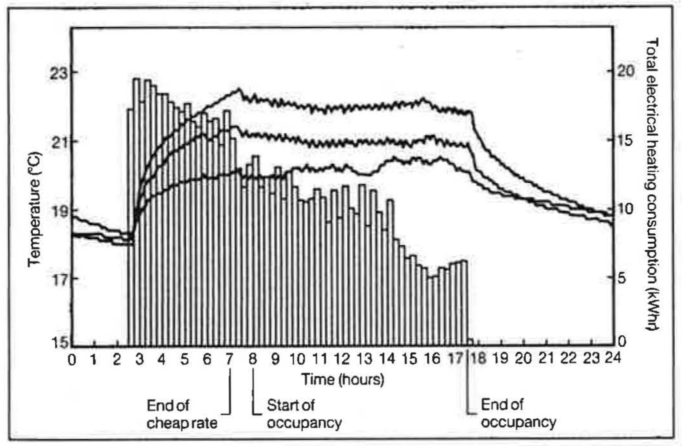
A number of lessons have been highlighted by this work[2], including:

□ the desirability of giving occupants greater control over their environment;

□ the need to balance reduced energy use associated with the implementation of relatively high-tech, energy efficient features against difficulties associated with the complexity (and hence additional costs) of such approaches.

BRE is investigating the costs and benefits of adopting electric heating in highly insulated office buildings. As well as simplicity of design and installation (resulting in fewer operational deficiencies), electric heating potentially offers several other benefits, including reduced capital costs, low maintenance overheads, and increased flexibility. These benefits need to be balanced against other factors such as the lower cost of fuels associated with more conventional systems (eg gas fired central boiler circulating hot water to individual emitters), as well as concerns about environmental matters.

The LEO was refurbished during the summer of 1988 to allow an independent assessment of the concepts associated with electric heating in highly insulated, naturally ventilated buildings. Information about the 1988/89 heating season has been used to improve guidance on the design, control and use of electric heating. This guidance is to be published shortly in the form of a BRE report[3].



Above, figure 1: Electrical demand for heating and three room temperature profiles in the LEO in its all-electric mode of operation.

Why electric heating?

The presence in buildings of a wide range of design, installation, commissioning, and operating problems associated with building services is unfortunately not uncommon. A requirement of heating system provision in future buildings may therefore be the necessity for systems that are simple to design, install, maintain and operate.

At the same time, it should be realised that as insulation levels in buildings increase, so does the proportion of heating requirement that is met by heat gains from occupants, office equipment, solar gain etc. A prime requirement of heating systems in highly insulated buildings must therefore be that they can accomodate adventitious heat gains. Failure to do so will mean an increase in internal temperatures, with the result being that occupants use window opening as a means of controlling temperature; a particularly inefficient control action.

All-electric, direct acting heating systems in naturally ventilated buildings would appear to satisfy the above requirements, ie simplicity with the potential for good local temperature control. If the realised performance and economics of such systems are good, they potentially offer a fundamental change in the way in which heating provision is provided in future highly insulated buildings in the UK.

A major argument against the use of electric heating is the cost of delivered energy compared to other fuels. The Electricity Council has argued, at least in the case of owner occupiers[4], that if capital and maintenance as well as energy costs are considered, electric heating systems in highly insulated buildings become economic. This approach is called life cycle costing (lcc). BRE's work in this area indicates that the justification of electric heating on a lcc basis needs to be carefully evaluated at each site, as there are many influencing factors:

□ building value;

□ construction materials;

□ building and services design;

□ local factors such as availability of gas/size of electricity supply;

□ assumed maintenance and energy costs.

The installed system

The heating system is split into nine zones. Each zone is controlled via a BRE controls test facility designed to emulate all the commercially available control systems that can be applied to electric systems. As well as one control sensor installed in each zone, overall building performance is comprehensively monitored.

The heating system has 120 panel heaters at a total rating of 96 kW, which includes a design oversizing factor of 20% beyond that necessary to match steady state design conditions. Some areas were sized in excess of this value in line with past experience which indicated that some areas of the building had heat losses greater than design.

Operating experiences

Overall the design and use of the electric heating system has proved itself to be a simple and viable option. Problems associated with the electric heating system hardware were trivial (apart from commissioning). The only difficulties encountered being two small wiring faults, and one panel heater failure.

Panel heaters installed in the LEO were designed for the domestic market and suffered shortcomings in terms of their performance in a commercial environment. For example, the commissioning of the heaters proved to be a much harder task than was initially anticipated, and surface temperatures were in some instances excessive – beyond 80°C – and gave rise to some occupant complaints. As a consequence BRE has developed a specification for a panel heater tailored to the commercial environment[3]. Several manufacturers are now developing "commercial" panel heaters that largely satisfy BRE requirements.

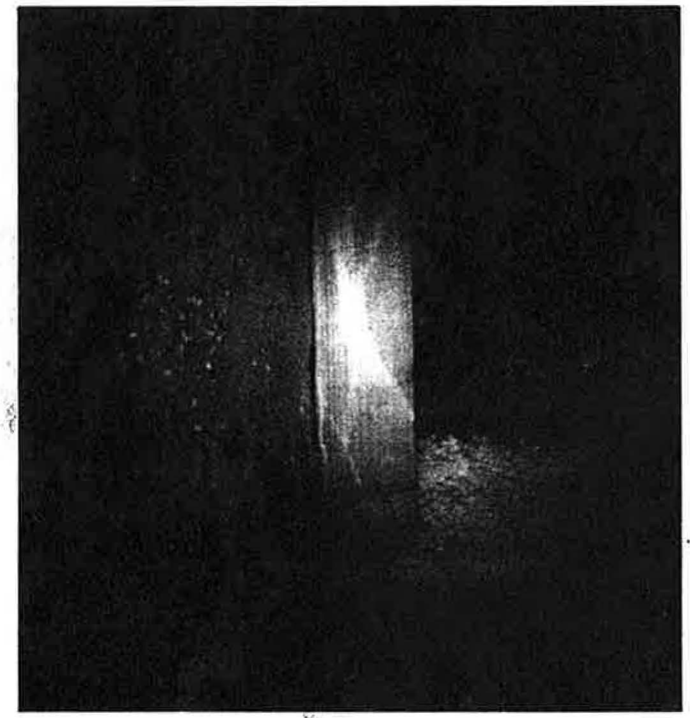
A number of different control strategies were evaluated, during both occupancy and preheat. The work has highlighted the importance of controlling on a basis of cost – the lowest energy use strategy evaluated in the LEO was not the cheapest control option. Costs were minimised by pushing demand into off-peak periods (ie overnight) by extending preheat durations. Annual heating requirements based on a CIBSE standard year have been projected as being between 40–50 kWh/m^2 per annum, depending on the control strategy adopted.

The lowest cost option consumed 45 kWh/m^2 per annum, using some 40% of electrical demand for heating during off-peak rates. The actual cost of the energy delivered depends upon the tariff structure employed and maximum demand charges – which relate in part to other electrical use. Predicted heating costs in the LEO using the most cost effective control strategy, for a standard CIBSE year, have been estimated at about £4000. A typical daily demand profile for electric heating in the LEO is given in figure 1.

User reactions to the system were generally favourable, apart from the problem of the high surface temperatures. In some offices occupants were allowed to adjust their panel heaters between set-points of 17-22°C. The degree of control provided by this is illustrated by three room temperature profiles in figure 1. In these instances occupants had adjusted their heaters to values between 17–22°C, although because of errors in the thermostat accuracy, actual temperatures of 19-23°C were measured. Temperature control can be seen to be very tight, indicating that adventitious heat gains are being successfully utilised.

Although the sizing strategy adopted in the LEO has proved acceptable, higher than expected heat losses in part of the building suggests that an oversizing factor of around 50% might be more appropriate to make the system more robust to construction anomalies.

In the past energy management has been shown to have a profound impact on energy use[1]. It has been estimated that good energy management of electric systems saved approximately 20% of energy use. This is important given the price of delivered energy relative to other fuels.



Above: Missing insulation in a wall cavity. The concept of electric heating in buildings reinforces the need for good quality control during construction.

Construction quality needs to be assured for a building that is electrically heated. Unfortunately in a large number of buildings actual heat losses are significantly greater than design because of a failure to maintain quality during construction, or a lack of adequate detailing. Because of the relative costs of delivering energy from electricity compared to more conventional systems, such failures have a greater impact on running costs.

The environment

The current concern with the greenhouse effect and ozone depletion has highlighted the increasing concern that is being shown about the impact of buildings on the environment.

Delivered energy from electricity creates significantly more carbon dioxide than an equivalent amount of energy delivered to a building by, say, natural gas – the ratio being approximately 4·5:1. However, this value is open to much interpretation. For example, methane is 27 times as potent a greenhouse gas as carbon dioxide, and some methane is lost during the production, distribution, and use of natural gas. In addition, insulation standards associated with electrically heated buildings are substantially higher than current regulations dictate. This reduces, by as much as half, the actual heating requirement of an electrically heated building, compared to one built to current regulations.

Given the increased awareness of the environment, it is conceivable that the desire to be "environmentally friendly" may have an impact on the market's perception of future building values, and hence on the design of the building and its services. Other factors such as possible changes in fuel prices and tariff structure, perhaps due to a "carbon tax", may also affect the overall economic decision as to the final form of a building's services.

Finally, as we approach the middle of the next century, a time when many of today's buildings will still be with us, global warming may significantly alter a building's requirements. There may be a greater demand for cooling and less for heating. The question of how the building industry should accommodate such potential changes is as yet unanswered.

Future work

BRE is currently engaged in a direct assessment of modern gas/electric heating systems in the LEO. For this work the conventional gas fired wet heating system and the electric heating system have been refurbished in line with today's technology. The gas system now has condensing boilers operating under state-of-the-art controls, and the electric system has been upgraded in line with experience.

In addition, the building's mechanical ventilation system – unused during 1988/89 – is being refurbished to accommodate a cross plate heat exchanger with the option for either combined use with an all-electric (heat pump) or gas (heater battery) option. During 1989/90 the building will be operated half and half in the gas/electric modes using natural ventilation. In 1990/91 these systems will operate in conjunction with the mechanical ventilation system.

This work is being funded, as part of BRE's Technical Consultancy service, by a number of organisations including: British Gas; The Electricity Council; Broag; Staefa Control System; Dantherm; Danfoss; Paterson Heating; and Delcomm.

Conclusion

BRE has undertaken a detailed study of the performance of a decentralised electrical heating system in a highly insulated, naturally ventilated office and can now provide independent selection, design, installation and operational guidance to the UK market.

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[2] John, R W; and Salvidge, A C. *The BRE low energy office – five years on.* BSERT Vol 7, No 4 1986.

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[4] The Electricity Council. *Energy efficient designed buildings: financial appraisals.* EC4972/8.87.