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AN ALL ELECTRIC BRE LOW ENERGY OFFICE - THE WAY FORWARD?

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The BRE Low Energy Office (LEO) building was among the first buildings designed in the UK with the aim of minimising energy use. Some seven years of operating experiences of the building have been used to assess its long term performance. The main lessons from the building include the desirability of giving occupants greater control over their environment, and the need to balance reduced energy use associated with the implementation of relatively "high-tech" energy efficient features, against problems linked to the complexity (and hence additional costs) of such approaches. In order to provide heating systems that should be easier to maintain in the long run, BRE is investigating the long term benefits of adopting electric heating in highly insulated office buildings through an assessment of such a system in the LEO.

1. BACKGROUND.

The BRE Low Energy Office (LEO) was amongst the first buildings constructed in the UK with the aim of minimising energy use. In practice the building uses only between one half to one third the energy of earlier designs. The design of the LEO (figure 1) was finalised in 1978 and incorporated those energy efficient features, which at the time, were considered desirable to minimise the building's energy use whilst constructing the building within the then applicable cost limits. The LEO provides almost 2000 sq.m. of predominantly cellular accommodation, for about 70-80 personnel. The building's design philosophy has already been extensively detailed elsewhere (1,2). Briefly the main features of the LEO are:

Building Fabric: The structure was designed to 'cushion' the environment from external climatic variations as far as practicable, with the building services providing only 'fine tuning'. The building is of moderately heavy construction (response factor of approximately 6), and, by the standards of 1978, was relatively well insulated (better than the then applicable building regulation values).

Heating Plant: A boiler room contains three gas fired modular boilers, supplying water to: finned elements housed in the perimeter convectors; to the ventilation system's heater battery; and to domestic hot water calorifiers. The heating circuit is broken into two zones, north, and south. Central control was initially provided by time clock, compensators and optimiser, with local temperature control being provided by thermostatic radiator valves (trvs) with remote sensors.

Ventilation system: During winter the windows were designed to be locked, so as to minimise air infiltration rates. Fresh air requirements are then satisfied by a mechanical ventilation system that incorporated a heat wheel to recover heat from the building's exhaust air. In summer to avoid the need for air conditioning, windows are openable, with external blinds providing an additional means of protecting against overheating. The mechanical ventilation system is turned off in summer.

Experience of the LEO has an important role to play in future low energy designs because:

the impact of energy efficient features associated with the building's design, on overall costs and the internal environment, can be fully evaluated because of detailed, and long term, monitoring of the building, combined with the availability of extensive on-site expertise to interpret that data;

the building has already been successfully used to develop and evaluate a number of innovative energy efficient features. The LEO offers a unique tool to assess future design / control strategies, and to compare these with earlier experiences.

When considering the performance of the different features of the building, it should be realised that the building's design team were constrained both by the need to remain within the (then applicable) PSA cost limits, and by the absence of previous operating experience of energy efficient buildings. There is a need to acknowledge the building's owners (PSA) for allowing full details of the building's performance to be made available (warts and all): an enlightened approach that should be encouraged throughout the industry.

This paper reassesses the performance of energy efficient features included in the building's design in the light of seven years of operating experience, and illustrates how these findings led to the decision to evaluate an all electric heating system in the LEO. Experiences of the all-electric heating system to date will also be described.

2. REALISED PERFORMANCE - LEO AS DESIGNED.

Heating System Performance - Temperature Attainment.

An initial failure to achieve target internal temperatures in the LEO on a substantial number of occasions, figure 2(a), has been attributed to a combination of inappropriate controls and a level of installed heating system capacity that did little more than match steady state design requirements (3). Current guidance (4) would allow for an oversizing factor of some 30%. In order to improve optimum start performance the "BRESTART" (5) optimum start algorithm has been used since the 1984/5 heating season, and this has led to a significant improvement in the attainment of target temperatures (see figure 2(b)). The significant improvement in performance was achieved for a number of reasons including: a better predictive schedule; self-learning resulting in better selection of control parameters; and an ability to identify when there is insufficient heating system capacity to allow intermittent heating, and therefore allow continuous heating (using night-setback) (2). Because "BRESTART" was able to accurately predict preheat times, the improved attainment of comfort conditions was achieved with little additional energy expenditure.

Heating System Performance - Energy Use.

Table 1 illustrates energy use and internal temperature over the first five years of occupancy. Results are not given for the last two years of operation because the data has been distorted by an extensive number of experimental trials. High energy consumption during the first year can be attributed to commissioning. The lowest energy consumption figures are those for 1982/3 -the period covered by the initial report on the LEO (1). Energy levels increased during 1983/4, a period when the building was not being intensively monitored, i.e. the building's operators no longer received feedback from monitoring work. Over the last two years energy use returned to levels similar to those for 1982/3, even though there was an improvement in the attainment, and level, of comfort conditions. This was attributed to the use of the new control and heating regimes, which allowed a more consistent, and energy-efficient, control over the building, and the fact that since the building was being monitored, time clocks, boiler efficiencies etc. were once again optimally adjusted.

Table 1. Energy consumption, and environmental conditions in the BRE Low Energy Office, 1981-86.

Heating season	1981/2	1982/3	1983/4	1984/5	1985/6
Gas consumption (degree day corrected (Oct. to April) (MJ/m^2)	524	460	530	476	476
Internal Temperature at the Start of Occupancy (^{o}C)	-	18.6	18.4	19.1	19.3

Heating System Performance - Thermostatic Radiator Valves.

When functioning correctly, thermostatic radiator valves (trvs) have been found to successfully utilise extraneous gains. However, the longer term performance of the particular trvs installed in the LEO has proved disappointing. Trvs initially failed frequently due to a combination of design and installation faults, and even when replaced by an improved design, some trvs continued to fail. Because of failure, or tampering by occupants, by June 1985 some 40% of trvs were effectively disabled, and a significant number remain so.

In the LEO, because of the characteristics of the installed optimiser and trvs, trvs were found to adversely affect optimum start performance by reducing emitter output during preheat as target temperatures were approached. This made the attainment of target temperatures less likely. During 1985/6 this effect was limited by adjusting trv and optimiser set points to minimise the interaction between them. This effect illustrates the importance of having an integrated controls strategy.

In this particular application (by no means unique), the trvs installed have failed to perform adequately in the long term. This is not to say that trvs cannot provide good long term local temperature control in all cases, but that in order to do so, care must be taken in their selection (e.g. type, sizing etc.), installation, and during later operation.

<u>Other Control Issues</u> - External Blinds.

The external blinds are an important design feature of the BRE LEO. They protect the building from overheating in the summer, so allowing window size to be optimised on the south face of the building (45% of facade) by balancing fabric heat losses with solar gain and the availability of daylight. Although the potential existed for a very complex set of controls to be used with the external blinds (e.g. inhibit blinds if external temperatures are less than target temperature), control of the blinds, other than outside the occupancy period and at high wind speeds, has been left to the occupants. This has been done for a number of reasons:

i) occupants prefer to have control over their blinds;

ii) the potential for energy savings from the use of the automatic control is probably small because occupants tend not to use them very often in winter, and in any case, a large proportion of heating requirements occur outside of the occupancy period;

iii) such strategies require the regular maintenance of associated sensors (e.g. solarimeters).

The maintenance of the blinds, and associated control equipment, has proved to be a significant expense. The on-going costs of maintaining relatively complex systems needs to be realised early on. Failure to maintain such systems, either through neglect, or as a cost cutting exercise, will inevitably result in degraded performance. It should also be realised that control systems and associated equipment do not last forever, and will one day need to be replaced. The simpler a system, then the more likely it is that long term costs will be minimised.

<u>Other Control Issues</u> - Lighting Controls.

The lighting control system installed in the LEO was based on the use of external photoelectric sensors, combined with simple automatic time switching. The selection of this control system was made at a time when little guidance was available on the choice of lighting controls. The system proved difficult to commission, and some complaints were received about the way in which occupants had no over-ride facility. Disconnection of the lighting controls in the LEO had a minimal effect on electrical consumption. This finding is predicted by, and has added further confidence to, the use of BRE Digest 272 (6) on lighting control schemes, written subsequent to the building's design, which recommends that the only lighting control strategy likely to be economically justifiable for buildings similar to the LEO (i.e. those providing predominantly cellular accommodation) is one based on simple time switching. This is due to the fact that, in cellular accommodation, occupants tend to switch lights in a fairly rational manner.

<u>Other Control Issues</u> - Window locking in winter.

The locking of windows in the LEO during winter was incorporated into the building's design in order to control ventilation losses. In practice the locking of windows proved difficult in that: it was never quite certain when they should be locked (there is no definite summer/winter handover date); occupants preferred having the option to open windows. Locking of windows was discontinued because of these problems. Experience has indicated that so long as internal temperatures are tightly controlled to 19.0^{o}C occupants seldom take up the option to open windows in cold weather as this lowers internal temperatures below acceptable comfort levels.

The presence of a wide range of design, installation, commissioning, and operating problems is unfortunately not unique to the LEO, and indeed, in BRE's experience, is fairly typical of the building stock as a whole. This is not to say that even complex building services cannot be made to work efficiently, but given the design, installation, commissioning and operating environment of most buildings, experience suggests that it is unlikely.

3. ELECTRIC HEATING - THE WAY FORWARD?

If it is accepted that the simpler the system design, the more likely it is that the building services will perform well in the longer term, then 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 requirements that are met by heat gains from occupants, office equipment, solar gain etc.. A prime requirement of heating systems in highly insulated buildings, if energy costs are to be minimised, and good local temperature control provided, must therefore be that they be able to adequately accommodate adventitious heat gains. Failure to do so will result in an increase in internal temperatures with the consequential result of occupants using window opening as a means of controlling temperature - not a particularly efficient control action.

All electric, direct acting, heating systems would appear to satisfy the above requirements - i.e. a simple system capable of providing good local temperature control. If the realised performance of such systems, and their economics, are good, they potentially offer a fundamental change in the way in which heating provision is provided in future highly insulated buildings. The main argument against their use must be the cost of delivered energy compared to other fuels. The Electricity Council have argued that if a Life Cycle Costing (LCC) approach to building services is made (7), then "all electric" heating systems are economic. BRE is currently evaluating this assertion through operating experience in the BRE LEO (see later), and an independent assessment of the LCC approach.

3.1 TRIAL STUDY.

In order to evaluate the concept of direct acting electric heating, insulation levels were initially improved in just four rooms in the LEO, by installing double glazing incorporating low emissivity glass with argon fill, in a thermally broken aluminium frame, and a direct acting electric heating system installed. The heating system comprised of 1kW electric heaters in each room controlled through a remote thermostat via BRE monitoring and control equipment. During the trial period the building's mechanical ventilation system functioned as designed, supplying tempered fresh air to all offices. Results from the trial study were to be used to assess what could be achieved with an electric heating system. The results from this trial system were:

Improved Internal Temperature Control.

Figures 3(a),(b) illustrate room temperature profiles for all four rooms incorporated in the pilot study both before, and after, the introduction of individual electric heaters. In figure 3(a) the temperature imbalance that is indicative of centralised heating systems is apparent, and is attributable, partly at least to the removal / occupant adjustment of trvs With the use of individual electric heaters, each with its own localised control, internal temperatures are much more closely controlled to target values figure 3(b). The data in both cases comes from days with no occupancy effects, with low solar gain values, and are for days where ambient temperatures are close to design values.

Heating Demand Breakdown.

Figure 4 illustrates electrical demand for heating in two of the four rooms studied, together with internal temperature profiles in each of those rooms. Demand occurred predominantly (70%) during the preheat period, although it should be emphasised that the building's mechanical ventilation system was supplying tempered fresh air as usual during the trial period. In the four rooms monitored, annual heating requirements have been estimated at around 35 kWHr/sq.m./annum, although it is difficult to be sure of the exact figure because only four offices (located on the first floor of a three storey building) were operating under an "all electric" regime, while the rest of the building was operated as usual.

Occupant Effects.

One of the occupants in the four room trial study was a reasonably heavy smoker. In this particular room it was found that heating requirements were significantly higher than in the other three (>50%) presumably because he increased the room ventilation rate by opening his window.

4. AN ALL ELECTRIC BRE LOW ENERGY OFFICE - CURRENT EXPERIENCES.

4.1. Design.

The conventional way to estimate heating system sizing is to consider the steady state losses during the preheat period, and then to add on an appropriate oversizing factor (4). There are a number of reasons why this may not be the best solution for electrically heated highly insulated buildings. If electricity is to be used to heat a building, then to minimise costs it is necessary to maximise demand during off-peak rates. Past experience (3) suggests that one way on way of achieving this is to tightly size plant. At the same time, in order to minimise the maximum demand charge, it is may be desirable to minimise installed load (although load shedding can also be used). In naturally ventilated buildings, demand during the preheat period should occur predominantly due to fabric heat losses, whereas during occupancy a much larger proportion of demand than usual will be required to satisfy ventilation requirements through occupant use of windows / trickle vents (although adventitious heat gains should help matters). In the LEO the heating system was sized to satisfy demand during occupancy under design day conditions (assuming no internal heat gains). Variations in the (radiator sizing) / (design demand) ratio occured because of, for example, the availability of emitters at the necessary ratings (e.g. 500, 750, 1000 watt heaters are available from one manufacturer but not the 567 watts, say, that might be the calculated demand). Rooms with different ratios of (radiator sizing) / (design demand) are being studied to provide improved sizing guidance on the optimal sizing criteria.

The wiring for the system is configured into six zones (north and south on each floor).

4.2. Installation.

The system had to be installed whilst the building was occupied. This was carried out with a minimum of disturbance to occupants, helped in part by the pre-existence of cable runs for the wiring. It was intended that the new switching gear be placed in the existing electrical substations of the building but this was found to be impossible because of space limitations. If there were a need for larger electrical switching rooms in new build, however, this should be more than offset by the absence of a more conventional heating system complete with its central plant room.

The capacity of the existing electrical mains cable to the building was insufficient for the heating system. The installation of an extra cable to the building proved an additional expense. Had the local transformer been unable to support the additional electrical load, the costs of installing an electrical heating system would have risen dramatically.

Several of the heaters were dented and/or scratched during installation and later use. A more robust design, suitable for commercial applications, may be desirable.

4.3. Commissioning.

Convector heaters from four manufacturers were installed in the building. Little consideration appeared to have been given to the way in which the products could be applied to commercial buildings and consequently:

- The temperature ranges available on the heaters are too wide for occupant control to be practical. Only one of the four heater designs lent itself easily to range limiting (that is allowing occupants some limited control over the set-point of the heater). After adjustment, by BRE, of control covers produced by one particular manufacturer, occupants in some thirty rooms in the LEO can adjust the set-point of individual heaters from between 17°C to 22°C.

- Three out of the four manufacturers provide no control covers for their heaters, BRE had to produce these so that individual heaters could be commissioned and then protected from occupant tampering.

- During the commissioning phase, only two brands of heater proved to have acceptably consistent control settings, i.e. all heaters could be set to approximately the same value, to give the same internal temperature. Because of this, commissioning was a much more difficult task than expected. Reliable (and consistent) long term thermostat performance is yet to be verified.

4.4. Operation.

The initial control strategy for the system is based upon the Electricity Council's recommendations (8). Each of the six zones has an individual, self-adapting preheat schedule (BRESTART) and these are set to achieve target temperature by the end of the cheaper electricity tariff period. During occupancy, internal temperature control is left to the heater thermostats, with an "upper limit" strategy being operated to deter excessive window opening (figure 5). This limits the time that electricity is supplied to the heaters according to external air temperature (EAT) and is analogous to weather compensated control of wet systems. For example; if EAT equals 0 ^{o}C then power is supplied to the heaters 100% of the time; if EAT equals 3 ^{o}C, power is supplied for 80% of the time, and so on. The performance of these, and alternative control strategies will provide guidance on the control requirements of electrically heated buildings. A number of specific factors are being examined:

* the effect of window opening to provide occupants with fresh air.

* the breakdown of electrical demand (on/off peak) and costs;

* occupant reactions to the system,

As this paper is being written, only limited operational experience is available. Figure 6 illustrates some of the preliminary findings. The figure plots total electrical consumption for heating, and internal temperatures for three rooms in the building. In figure 6, some 30% of electrical consumption occurs during preheat. In practice electrical consumption during preheat has ranged from 25-40% depending upon the control strategy adopted. Provisional electrical consumption values for heating as a function of external temperature are given in figure 7. Using the data available too date, electrical consumption for heating appears to be of the order of 50kWHrs/m^2/yr. Controls are currently being adjusted to see if consumption can be more effectively matched to the tariff structure. Figure 6 also illustrates that even though the "upper limit" control strategy is in operation during occupancy, internal temperature control has still proved to be good.

4.5 Flexibility.

* The all-electric heating system has proved reasonably easy to rearrange / upgrade in line with occupant requirements. However the flexibility of the system is limited by the initial design of the system (sizing of cabling etc.).

* It should be realised that in new build, if electric heating is included in the building's design, there is significantly less potential to install a different form of heating (say gas fired central plant) in the light of, say, changes in relative tariffs etc., than there is to retrofit electric heating in a building with a conventional heating system.

5. LIFE CYCLE COSTING (LCC).

BRE is undertaking an independent assessment of the use of LCC, including the sensitivity of various factors in the LCC approach. This work will then be used in conjunction with measurements of actual against predicted electrical use and cost to assess the overall economics of "all electric" heating. Results from the work on LCC are not yet available as this paper is being written.

6. FUTURE ALL ELECTRIC HEATING SYSTEMS.

BRE is investigating user requirements and a wide variety of control strategies so as to be able to provide both industry and users with improved guidance, and to direct longer term developments. For example BRE is developing control strategies that should allow the control of electrical heating on a basis of cost rather than energy (figure 8). In each case the assessment of the various control strategies needs to be based on a number of factors including the:

* effect on internal environment,

* impact on energy use and cost,

* requirements for changes in existing hardware / software,

* effects of increased complexity (e.g. on ease of use, maintenance levels) associated with the implementation of some of the more complex control strategies.

In particular BRE is investigating some of the changes in the medium - longer term that need to be made to existing panel heaters to allow improved user / centralised control. These include the possible use of: remote thermostats / sensors; the incorporation of intelligence in each panel heater, through the use of microprocessors (and associated controls software); and future communication and central station requirements.

7. CONCLUSIONS.

Some seven years of operating experience of the LEO have underlined the importance of:

* the need, and subsequent application of, appropriate design, installation, commissioning, and operating guidelines;

* an integrated approach to the design and provision of building services and control systems, considered in the context of the building fabric and other parameters such as the likely behaviur of occupants and occupancy patterns;

* long term performance monitoring to ensure energy efficiency is maintained;

* the need to consider factors affecting the long term performance of energy efficient measures (e.g. what maintenance resources are likely to be available).

The Building Research Establishment is currently using the LEO to assess the potential use of direct acting electric heating systems in commercial buildings in the UK. The trial will provide design, installation, commissioning and operat - ing experience and guidance to the industry and prospective users.

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Figure 1. The BRE Low Energy Office.

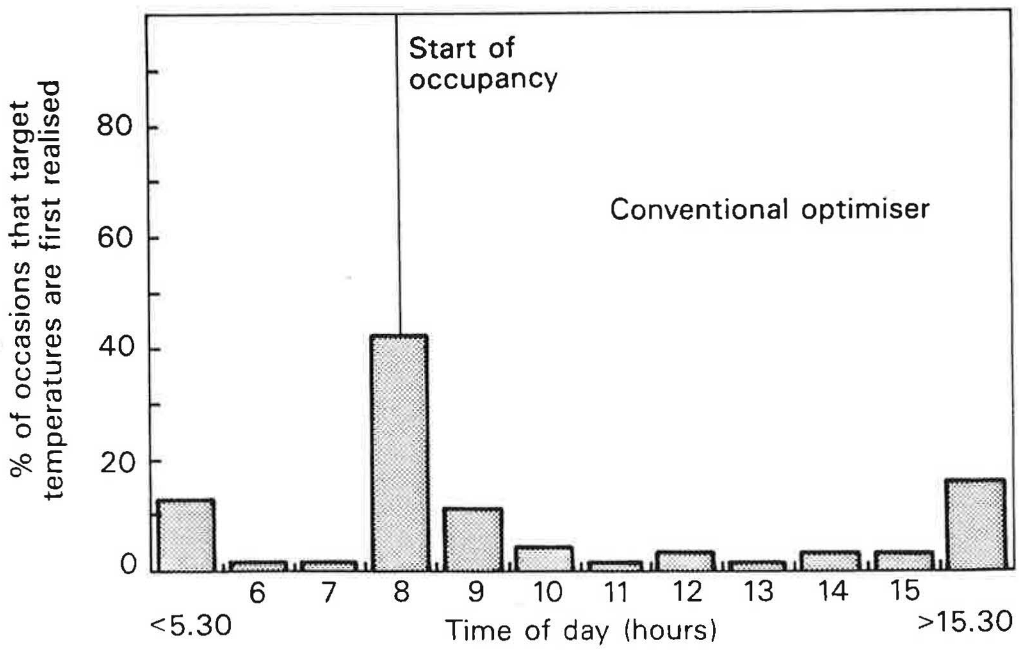

Figure 2(a). Optimum start performance in the LEO using a coventional optimiser.

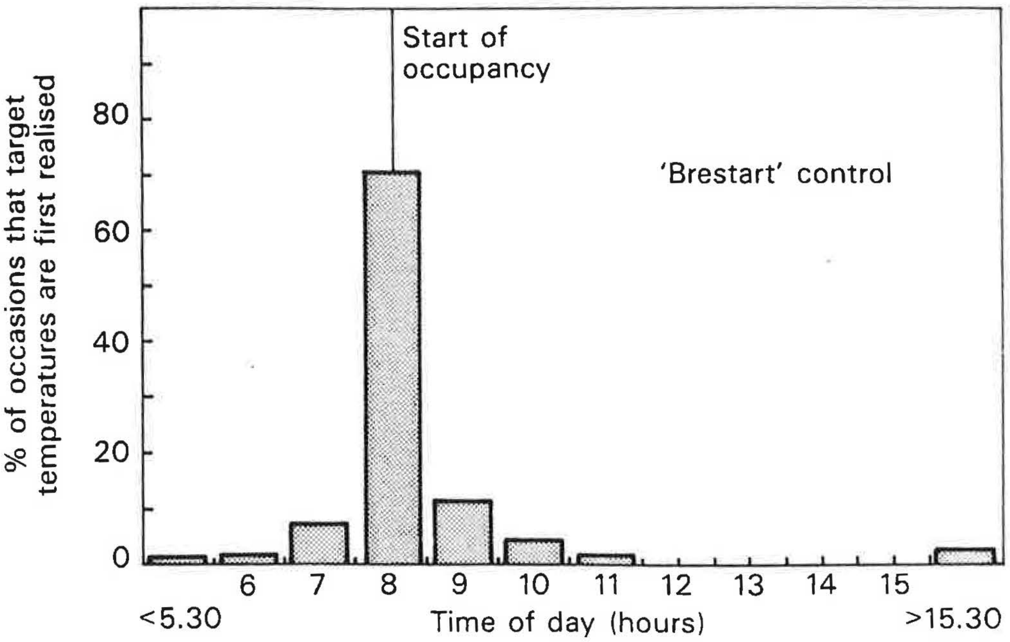

Figure 2(b). Optimum start performance in the LEO using "BRESTART".

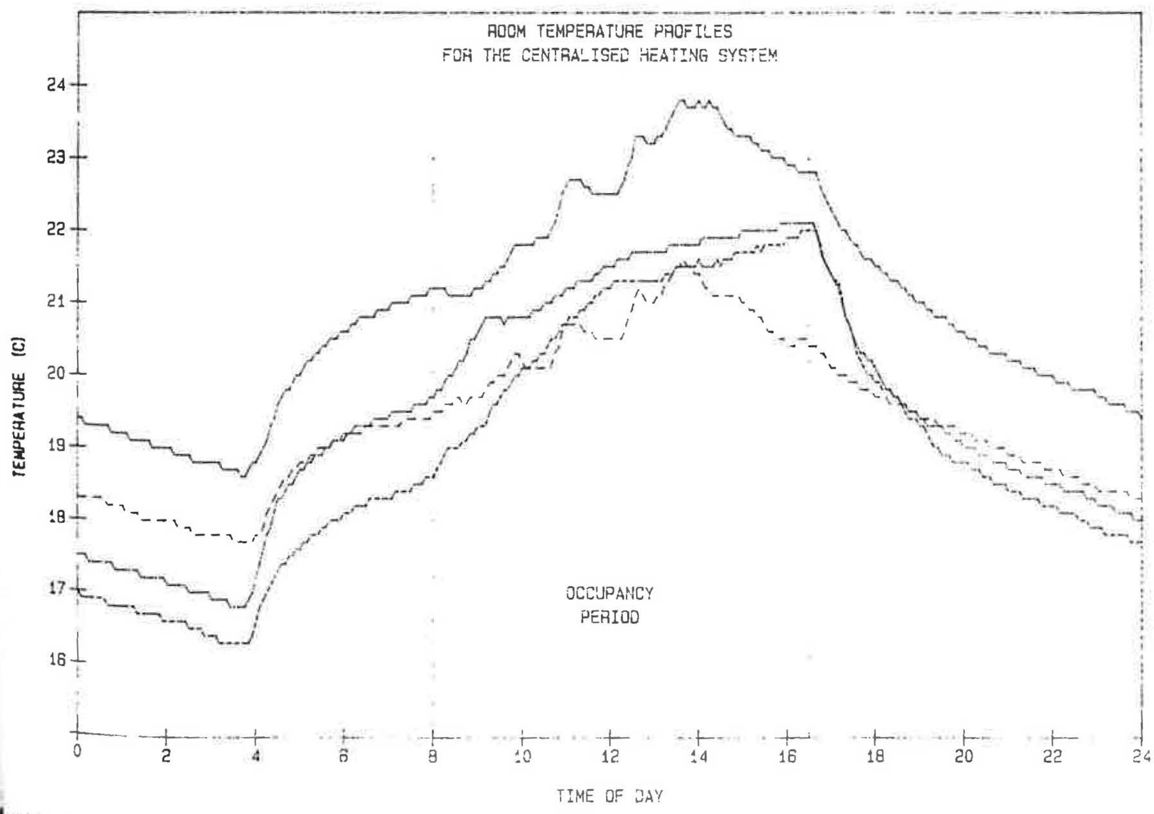

Figure 3(a). Typical room temperature profiles under the old heating system. Poor control is due to loss of trv control.

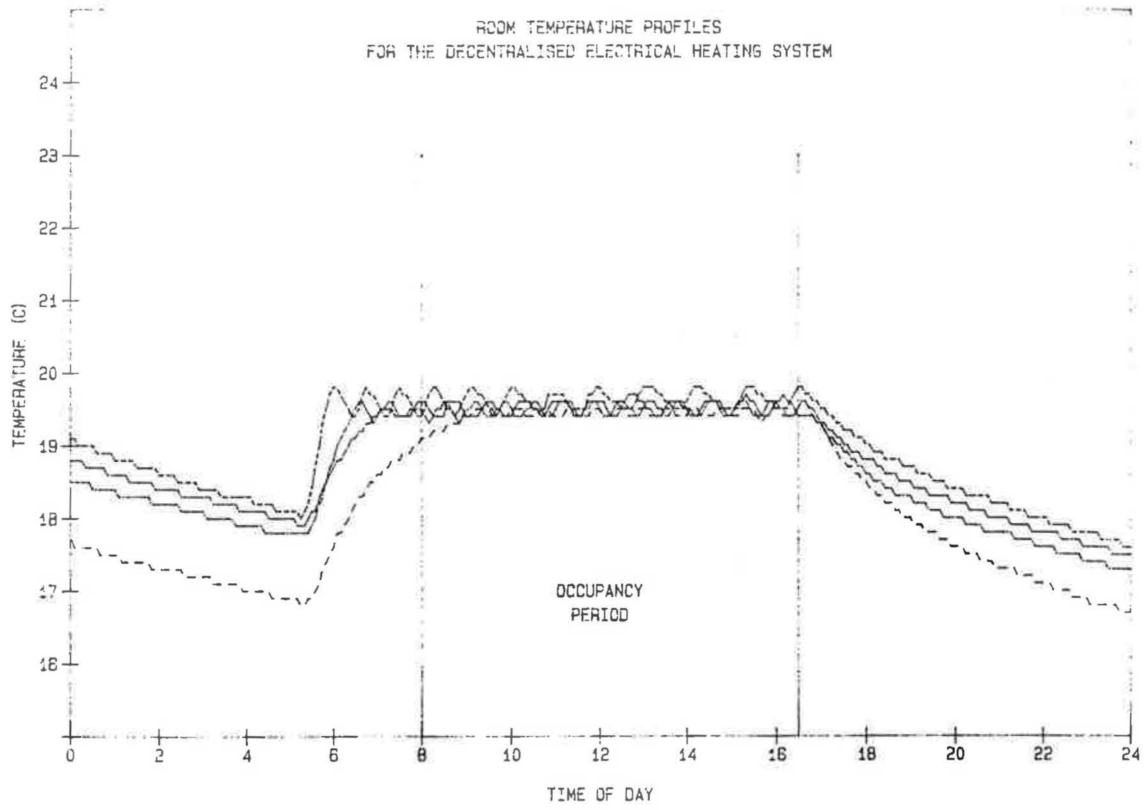

Figure 3(b). Temperature profiles using electric panel heaters with centralised control.

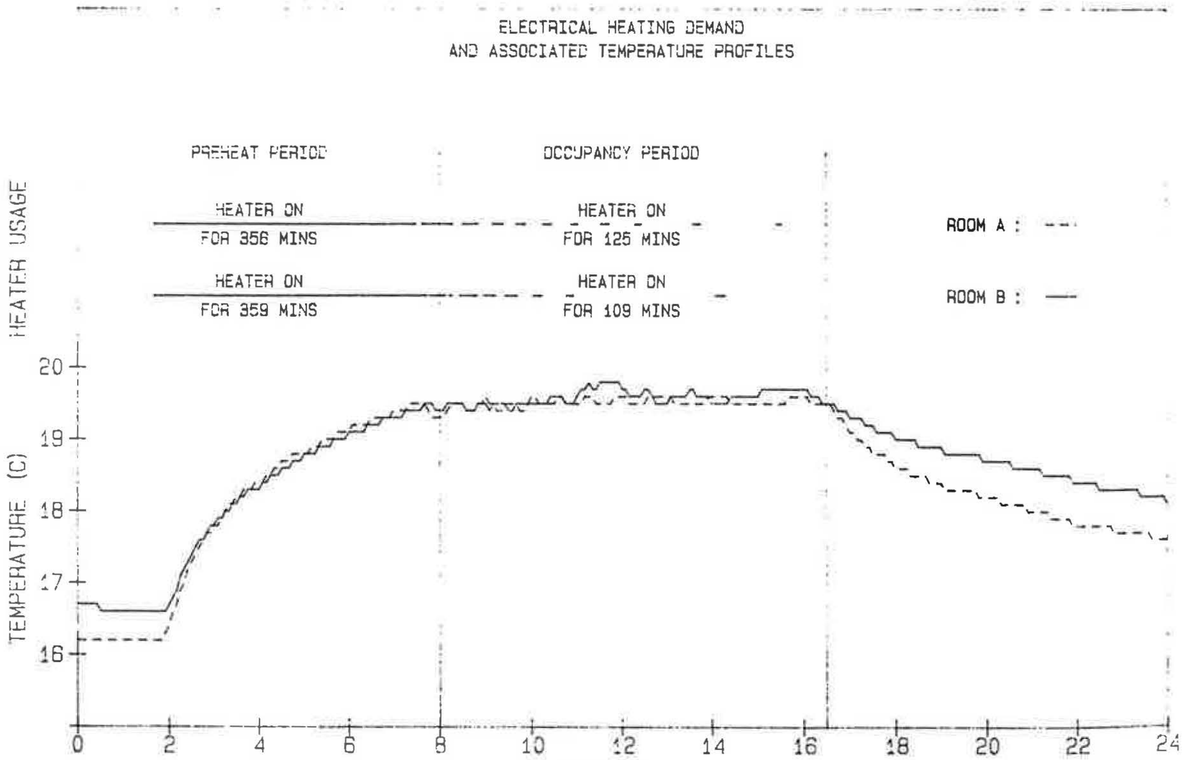

Figure 4. Temperature and demand profiles of two rooms using electric heating with the mechanical ventilation system supplying tempered fresh air.

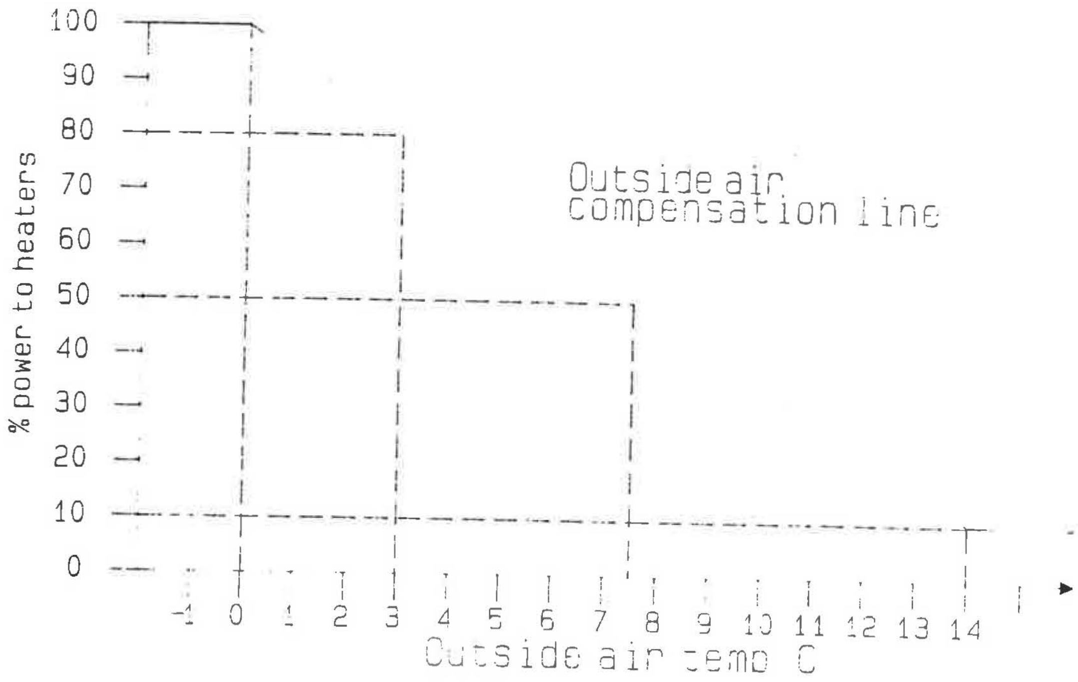

Figure 5. Schedule relating time heaters are allowed to be on as a function of external temperature.

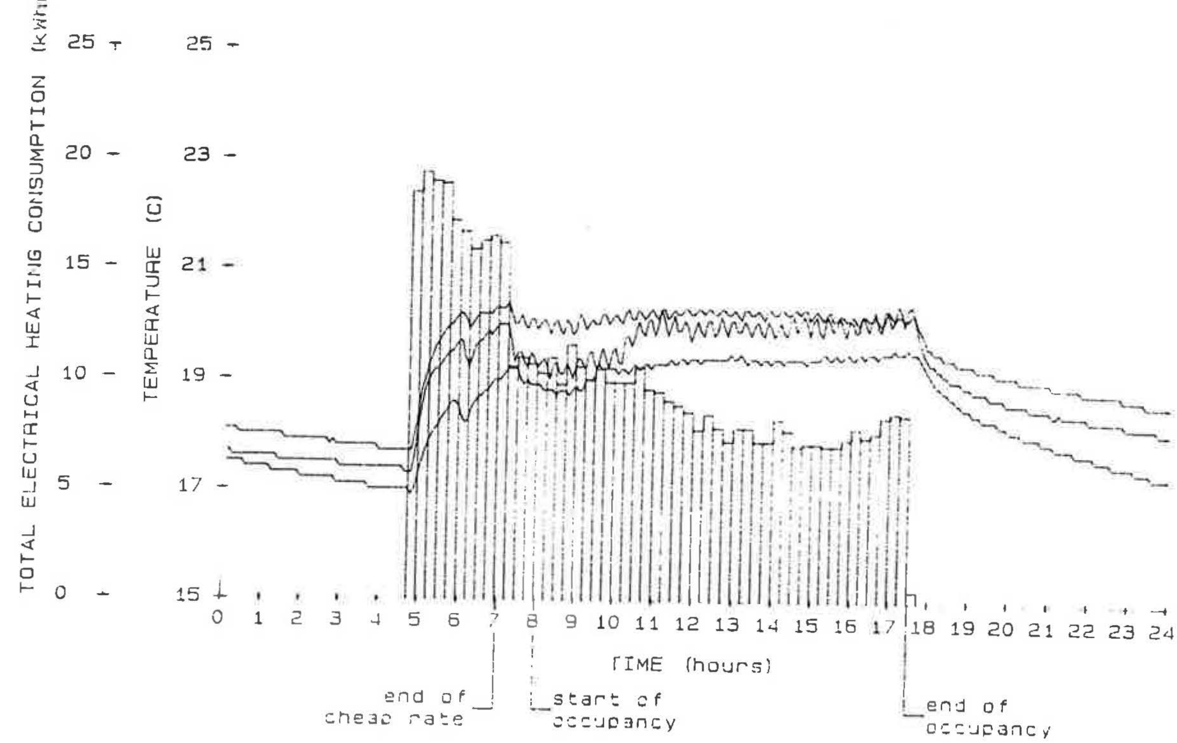

Figure 6. Typical daily electrical demand and temperature profiles in the LEO

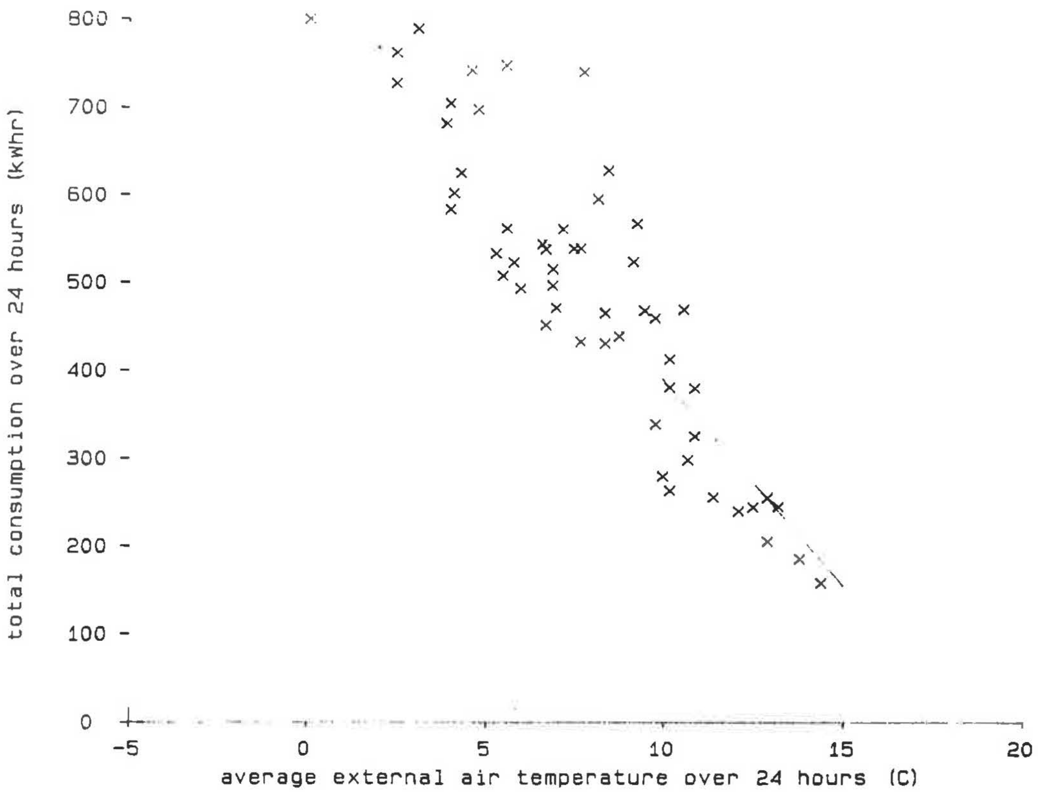

Figure 7. Daily electrical consumption for heating in the LEO as a function of external temperature. Results indicate an annual consumption of 50kWHr/m^2.

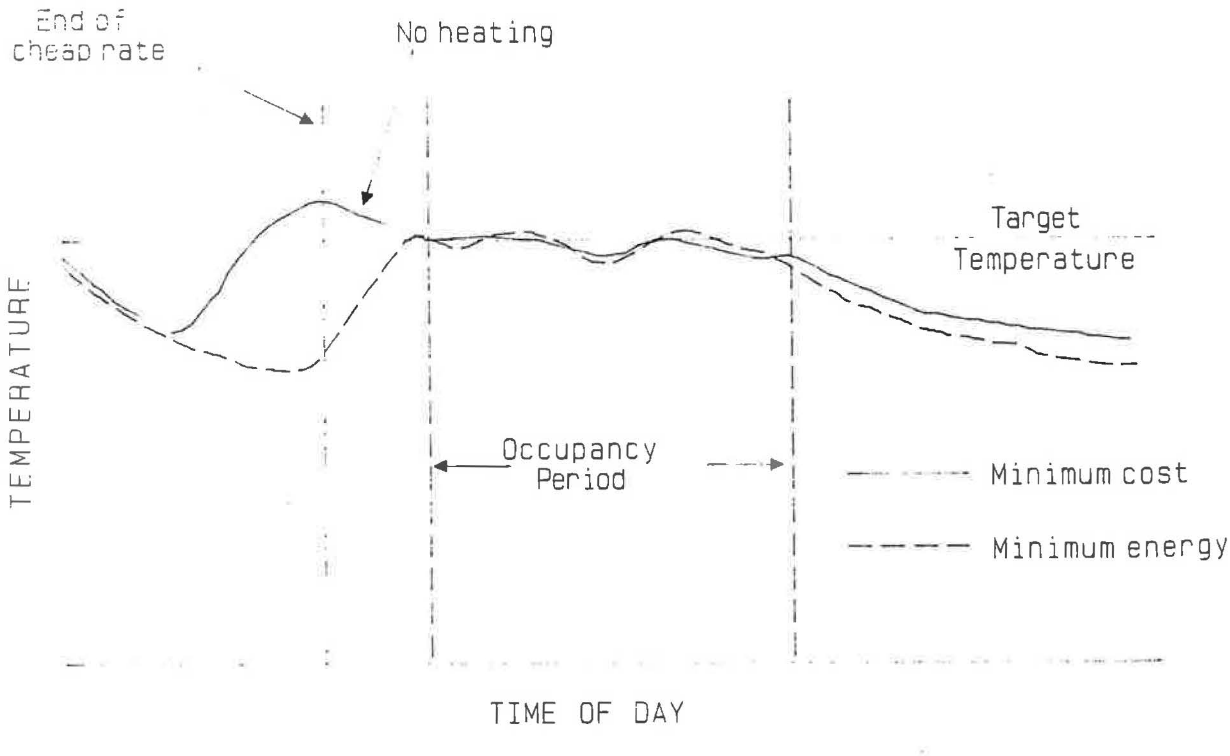

Figure 8. Possible control options provide for minimum energy use or minimum cost.