**TECHNICAL INFORMATION**

#3356

# Energy Efficient Design buildings: Offices

## Introduction

Commercial office buildings which are to be heated but not mechanically cooled can be built with a wide variety of insulation standards and heating systems. This booklet demonstrates that the option with the lowest cost in use combines a high standard of insulation with a simple but controllable electric heating system.

Such a combination can have total owning and operating costs for energy and maintenance comparable with fossil fuel fired heating systems in buildings insulated to current Building Regulations standards, but the total capital cost including the electric heating system and the higher standard of insulation is lower. Allowing for the extra space made available by the more compact electric heating system and the interest charges on capital makes the case even stronger.

This booklet gives recommendations for standards of insulation, infiltration control, air change rates and heating system control; these apply to any office building regardless of the heating system. They are not intended to be prescriptive because there are many ways of achieving the overall aim of a building envelope which intrinsically uses less heat energy to provide comfort for its occupants.

Recommendations are also made for the electric heating system and electric hot water services, both of which provide the heat input required at a low capital cost. Some designers may wish to combine high insulation standards with a fossil fuel fired heating system, but this does not represent the most cost effective solution. Such heating systems have a higher capital cost and/or an inability to be controlled flexibly, incur higher maintenance costs and take up more space. The running costs of such systems may be thought to be lower, but when the intrinsic heat energy requirements of the office building are so low, the fuel/energy cost is a less significant proportion of the total cost in use. The energy cost of fossil fuel fired plant is also adversely affected by combustion, distribution and control efficiency which can be lower than expected once the true efficiency of small plant operating for shorter heating seasons at part load is taken into account.

Suggestions are also made about centralised energy management control and monitoring and the omission of false ceilings. The former adds opportunities for further optimisation of heating system operation and for subdivision of heating costs where the office is sublet. The latter reduces costs and helps to control temperature swings at times of varying heat gains.

General comments are made in this booklet about the cost-effectiveness of the various components of Energy Efficient Design (EED) in the office building context, but for details of the cost in use appraisal see Technical Information – *Financial appraisals* EC4972.

### Scope

EED can be applied to new-build commercial office projects of 500-5000m$^2$ gross area, where mechanical cooling has not been specified. The concept is also applicable where major refurbishment (ie from structural shell) is being undertaken.

Buildings suitable for this concept are expected to be anywhere outside the major cities. City centre locations are unsuitable because airborne dirt, outside noise, the cost of land and the need to maximise the number of occupants in a given floor space, along with the ability to let property at higher rents, all lead to the need for air conditioning.

However, away from noisy dirty city centres, the principles of this booklet can be applied to heated-only buildings where summer temperatures can be controlled by opening windows.

### General principles

The aim is to provide cost effective thermal comfort for the office occupants so that they are at their most productive. The building envelope should be well insulated against conduction heat loss and should be capable of being well sealed to prevent inadvertent air infiltration. However, it should be able to be ventilated deliberately to deal with excessive heat in summer and with the day-to-day variations of levels of contaminants such as moisture, dust, tobacco smoke and body odour.

The conditions which provide thermal comfort vary from person to person. Therefore it is necessary to provide control over those conditions to small areas of the office, with an overriding control to prevent wastefulness. The heating system in a well insulated building, where the heat gains are likely to be a large proportion of the heat requirement, must be capable of supplying small amounts of heat as well as large amounts, so as to avoid wasteful overheating. To assess the performance of the heating system and to allow the heated area to be subdivided for apportionment of running costs in a multi-tenanted office, some form of central monitoring is needed.

To provide thermal comfort during summer without mechanical cooling it is necessary to lessen the swings of internal temperature by exposing the building mass to the sources of heat gain, to reduce solar gains in summer by window shading, and to allow for higher rates of ventilation.

## Insulation

Insulation standards for which a cost effectiveness case can be made in terms of current (1987) costs are given.

The U values represent levels which should be readily achievable with current building practice and construction standards. Where possible, further enhancement is to be encouraged, within the bounds of cost effectiveness over the life of the building.

Where building thermal mass is exposed to the building interior (ie the thermal response factor of the building is 5 or above), the preheat period will lengthen so that more of it is in the off-peak period. In addition, it will be easier to control temperature swings to avoid overheating in the summer.

**Recommended thermal response factor**

| | |
|---|---|
| Unoccupied period thermal response factor | Any* |

**Recommended U values**

| Building component | W/m²K |
|---|---|
| Wall | 0.35 |
| Roof | 0.25 |
| Floor | 0.35 |
| Window | 2.0 |

**Recommended window area**

| | |
|---|---|
| Window area as a % of external elevation | Any* |

*No constraints are placed on window area or thermal response factor. However, when the window area exceeds 25% or the thermal response factor is less than 5, it is recommended that the following checks are carried out and the results discussed with the building owner and preferably its occupants:

i) Predict internal temperature with 10 air changes per hour by opening windows on summer design day

ii) Assess number of days on which temperature exceeds a comfort level agreed with the building occupant eg 24°C, with 10 air changes per hour.

It is important that the overheating consequences on occupants of large unshaded glazed areas should be appreciated by the building owner. If he is not satisfied with the results of these checks, it will be necessary to consider changes to the structure or the addition of mechanical cooling to avoid discomfort.

The detailing of constructions with additional insulation should ensure that weather proofing is maintained and that cold bridges are avoided. Where this results in additional wall thickness, consideration should be given to cantilevered foundations to minimise extra cost.

Since the U values are averages over the whole building element, it is important that construction supervision on site should ensure that the insulation is installed as designed by the architect. Any shortfall from specification will detract from the cost effectiveness of the EED building.

## Infiltration control

Most building components are porous to the passage of outside air, which has two effects on the internal environment:

i) It dilutes the level of contaminants in the space – moisture, odours, and dusts.

ii) It substitutes for air which has been warmed to keep the occupants comfortable.

It is important to allow the former to take place, but the latter increases energy consumption. It should be appreciated that the level of air input needed for dilution of contaminants varies, as does the rate of infiltration, and these levels do not necessarily coincide at a particular time. Infiltration is typically dependent on wind pressure across the building and the stack effect of temperature differences between inside and outside of the building. Both driving forces are dependent on the microclimate around the building and since this varies from hour to hour, infiltration is uncontrolled and unreliable as a means of ventilation.

It is therefore necessary for the EED office building envelope to be well sealed to minimise uncontrollable infiltration and for passive or active controlled ventilation to be introduced to remove contaminants when they occur.

Infiltration takes place through a number of routes, not all of which are obvious:

a) Window and door leakage between the movable and fixed elements.

b) Leakage between window and door frames and the surrounding structural opening.

c) Junctions between structure and infill panels.

d) Through the porous materials comprising the building envelope itself.

**Recommendation for infiltration control**

a) Windows and doors: leakage between movable parts and frames:

Specify windows and doors to meet Class III BS 6375 Part 1 on air permeability. Such windows should have frame detailing and flexible seals to close all cracks in the component and yet allow window opening to take place for ventilation and escape. All regularly and frequently used main entrances to the buildings should comprise two sets of doors with closers and a lobby between to avoid the effects of deterioration of the edge seals.

b) Leakage between frames and structure:

High quality mastic injected into gaps under pressure.

c) Junctions between structure and infill panels:

Deal with by detailing to minimise openings while allowing for thermal movement and settlement. Incorporate neoprene gaskets between components to close off remaining openings.

Alternatively, avoid junctions altogether by homogeneous construction such as slip-form concrete walling or double thickness brick or blockwork skin. Openings between the inside of the building and the void in cavity construction, which is probably ventilated deliberately and/or has weep holes to drain excess moisture, can provide a path for unwanted infiltration.

d) Through porous building materials:

Incorporate a semipermeable membrane at some point in wall construction to minimise air movement but allow moisture migration outwards.

e) Supervision:

The quality of the building seal and hence its ability to control infiltration is very dependent on site supervision. It is important to ensure that the above recommendations for infiltration control are carried out adequately and that poor quality work is corrected.

**Controlled ventilation**

Positive, controlled ventilation is needed to provide adequate oxygen for respiration, to remove contaminants in office spaces throughout the year and to remove excess heat in summer.

In an office situation contaminants are released in the space at a fairly constant rate dependent on the number of people present. The contaminants include dust, dirt, carbon dioxide, body odours and tobacco smoke; usually it is the latter two which govern the volume of fresh air required. This volume is best calculated from the number of people present, and should be capable of variation should the requirement for contamination dilution or heat gain removal change.

Ventilation rates should follow CIBSE Guide recommendations (see section B2). In summary, for offices these are:

| Space | $m^3$/second per person |
|---|---|
| Open offices, some smoking<br>Cellular offices, heavy smoking<br>Conference rooms, some smoking<br>Conference rooms, heavy smoking | 0.008<br>0.012<br>0.018<br>0.025 |
| | $m^3$/second per $m^2$ |
| Corridors<br>Toilets | 0.0013<br>0.01 (subject to local byelaws) |

In an open plan office where there is an average of $5m^2$ per person, this would represent approximately two air changes an hour.

These air change rates can be brought about by controlled natural ventilation or by mechanical ventilation. The primary means of natural ventilation should not have to be by opening windows; sufficient air ingress can be designed to take place through trickle ventilators in window frames, with 'hit-and-miss' slider shutters to allow the occupants to control air movement through them when outside wind pressures are high.

However, to avoid overheating on warm days it will be necessary to allow windows to open, to offset internal and solar gains. Depending on the internal admittance, opening of windows may extend beyond summer particularly where false ceilings and/or low emissivity glass is used, but must be curtailed when there is a heating need. It is important to distinguish the need for ventilation to provide fresh air from the need to control overheating, both in the design of the EED building and in the education of its occupants. Since the heating is controlled to prevent waste by excessive ventilation during the heating season, it is essential that natural ventilation should be designed to be adequate without opening windows, so that staff can be told it is unnecessary.

## Heating system

The heating system for a well-insulated office building must be capable of:

i) Providing comfort and reliability.

ii) Operating efficiently at all times including when it is on a low load factor.

iii) Supplying enough heat to preheat the building to comfort conditions in time for the start of the occupied period.

iv) Supplying the heat requirements to just meet thermal comfort conditions without overshooting – a low thermal inertia heating system would be an advantage to simplify controls, save energy and improve thermal comfort for the occupants.

v) Supplying varying amounts of heat to different occupants.

In addition, it is preferable that it should have:

i) A low capital cost.

ii) A low maintenance cost.

iii) A low space requirement both in the occupied zone and in terms of plant rooms.

iv) An energy cost which is controllable and competitive with expectations in conventionally insulated buildings.

A direct acting electric space heating system in a well-insulated building meets all these requirements fully. A suitable system is panel heaters with built-in thermostats at each location, coupled with a centralised overall building heating control. Even though this is nominally an on-peak system, in practice a significant proportion of the heat energy will be needed during the off-peak period to preheat the building fabric (approximately 50% for a well insulated office with high response factor and average internal gains).

The low thermal inertia of the electrical energy distribution system makes for more precise control to match actual needs. Their unitary nature allows individual panels to be replaced if there is a maintenance need without affecting the integrity of the heating system as a whole and local thermostats allow comfort conditions to be selected for individual occupants.

Storage fan heaters may be used in circulation areas.

## Heating system control

With electric panel heaters, controls to perform all the following functions are readily available, allowing the system to take advantage of heat gains due to lighting, small power, solar gain through the structure and from the occupants, to offset heat energy required from the heating system, without wasteful overheating.

A heating control system must be capable of:

a) Controlling the temperature of the space close to the occupant to suit his or her thermal comfort needs, supplying just the amount of heat required from the heat emitter to maintain the comfort temperature.

b) Supplying the heat needed to bring the space up to the comfort temperature in time for occupation but no earlier (unless to do so costs less).

c) Relating the amount of heat supplied to each space to the expected requirement, given the outside ambient temperature, so that excessive heat loss (for instance due to an open window during the heating season) can be detected and some form of feedback given to the occupant of the space.

Notwithstanding requirement (a), the range of temperatures available to the occupant should be given an upper limit by the building energy manager to prevent wastefulness.

If the heating system has thermal inertia so that it cannot avoid emitting heat when the control system no longer calls for it, then the control system should be designed to anticipate the rising temperature to avoid overheating.

With the electric panel heaters described under 'heating system', a suitable control system can be provided at two levels:

i) Local to each panel heater, to provide the final control on heat input to suit the occupants' comfort requirements.

ii) Central to each letting zone, to provide optimum start and finish control, to check for heat energy wastage, to control the electrical maximum demand and to provide the basis for a monitoring and metering function (described later under building energy management system).

### Local control

At the local level, control to suit the room occupant can be achieved by a thermostat built into the panel heater.

Ideally this should have a physical limit to prevent temperatures being set high, but this can also be monitored by the central controller.

It is important to ensure the panel heaters work with switching differentials within 1°C. The room temperature swing will be minimised if this condition is met and the effects of maximum heating demand control reduced similarly.

To ensure that the room thermostats are operating to the specified limits each thermostat must be checked during the system commissioning. This commissioning must be rigorous, rejecting any thermostats that fail to perform to the specification.

It will also be essential to check the thermostats in a similar way during subsequent maintenance visits.

### Central control functions

*a) Zoned optimum start/stop function*

Central control is required for each zone (say all rooms on one building face within each letting area) to override local thermostats to prevent energy waste and to provide optimum start control. The wall surface temperature of each zone and outside air temperature should be sensed, to provide the central controller with the necessary input to calculate the optimised start and stop times, using the Building Research Establishment 'BRESTART' control algorithm. Each zone can then be provided with just the right amount of heat to bring it up to temperature in time for occupation, and no more.

*b) Zoned energy waste prevention*

The central controller should also be able to be programmed to deliver a limited amount of heat energy to each zone, scheduled against outside air temperature. This will enable unwanted heat loads such as that caused by an open window to be detected and feedback provided to the room occupant in the form of a falling temperature. The occupant should then realise that comfort conditions can be regained by closing the window.

*c) Multizone capacity*

For optimum comfort it is important that spaces with similar occupation and heat gain patterns are grouped together in each control zone, so that only groups of people who can interact with one another would experience the effects of the energy waste prevention as a result of the actions of one of them. In the case of disparate comfort requirements and/or personalities, the zones can be further subdivided or the schedule for that zone altered. The central controller for each letting zone should be capable of being interfaced with or becoming part of a building energy management system.

### Central control methods

With all the following methods of control the electric heating system design should conform to BS 5406, to minimise the voltage fluctuation effects of contactor and thyristor switching on lighting, business machines and other building services.

Briefly, BS 5406 implies that, for the worst case, the maximum single phase resistive load should not exceed 5 kW if the switching is to be as frequent as once per minute. This will ensure that there is no annoyance due to light flicker or other disturbance to the electrical services. The worst case would apply when the building supply impedance was 0.4 ohms. Typically, supply impedances are lower than this, which will allow higher loads to be switched; information on switching greater loads can be obtained from the Electricity Board Supply Engineer.

Where several zones are being switched, the compound effects must be considered to ensure that the switching frequency remains within the above limits. In this case, and in larger buildings where a single zone may exceed the maximum switched load, the supply can be controlled by several sub-contactors arranged to switch in sequence with delay timers between them.

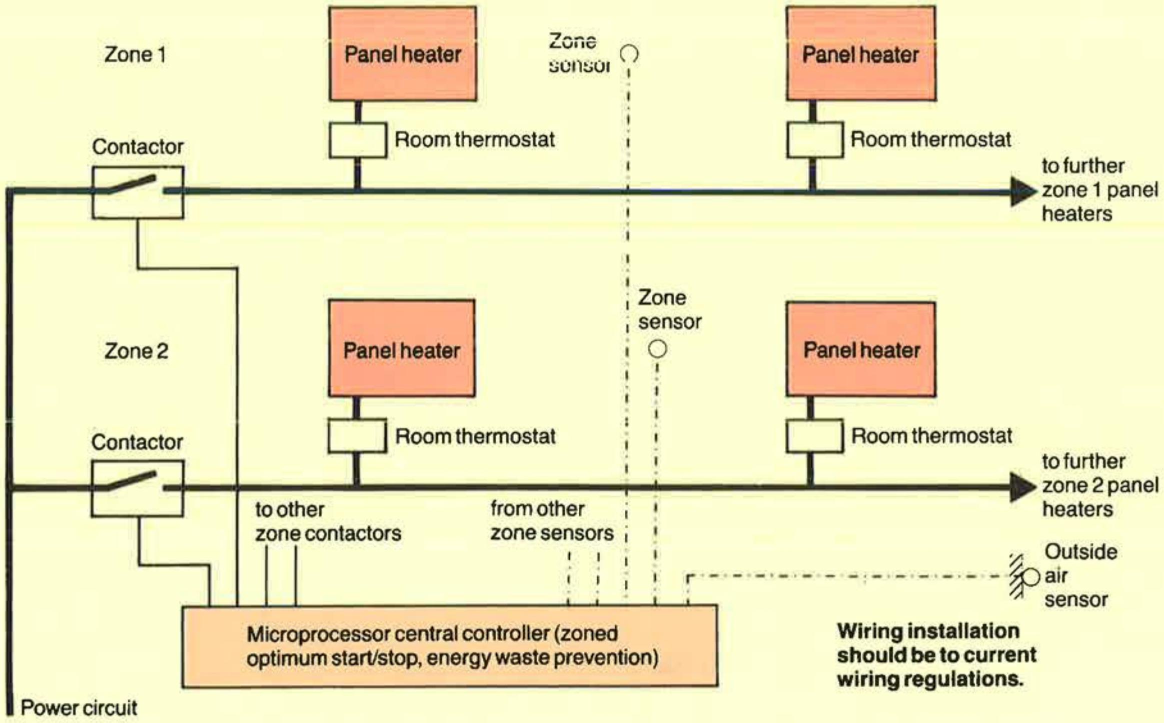

Fig 1. *Microprocessor control – wiring layout*

*(i) Microprocessor control*

The panel heaters within each zone would be supplied via a contactor controlled by the central controller (see Figure 1). Microprocessor controllers are currently available that are able to perform the functions of optimum start control and proportional load cycling for a number of zones simultaneously. Proportional load cycling means the controller energises a heating circuit for a period proportional to a preset outside schedule as in Figure 2(a). For example when the ambient air temperature is −1°C the heater would be available for use 100% of the time. Under these conditions it would operate at the dictate of the room thermostat. If however, the ambient temperature is 14°C the heaters might need to be made available for only 10% of the time. Under these conditions the heaters would be released for operation for say three minutes in every 30 minutes. The switching pattern would be preset as shown in Figure 2(b) and (c).

Two examples of switching patterns for the zone contactor have been shown: one for a lightweight construction where the heater operation is more frequent and one for a heavyweight construction where a longer period between operation is acceptable. In a lightweight building there would be little thermal mass and temperature variations could become large. For this reason the controller switches on one minute in every 10 to achieve a 10% load while avoiding a large temperature swing. Conversely a heavyweight building would have sufficient thermal mass to afford a less frequent switching pattern of three minutes in every 30.

*(ii) Thyristor control*

An alternative to the central microprocessor control of the heating maximum demand is the application of a Proportional Thyristor Control unit. The thyristor controller would be driven from a simple proportional controller that provides an analogue signal proportional to the ambient air temperature. The control arrangement would be on the basis of providing one thyristor unit and proportional controller for each zone. For large multi-zone buildings the cost of employing this type of control would be greater than applying the microprocessor proportional load cycling system because of the need to supply a self contained control system for each of the zones. If however, the building operates on only one or two distinct zones the thyristor control system would be more competitive. In the case of the thyristor controller a separate optimum start controller would also be required.

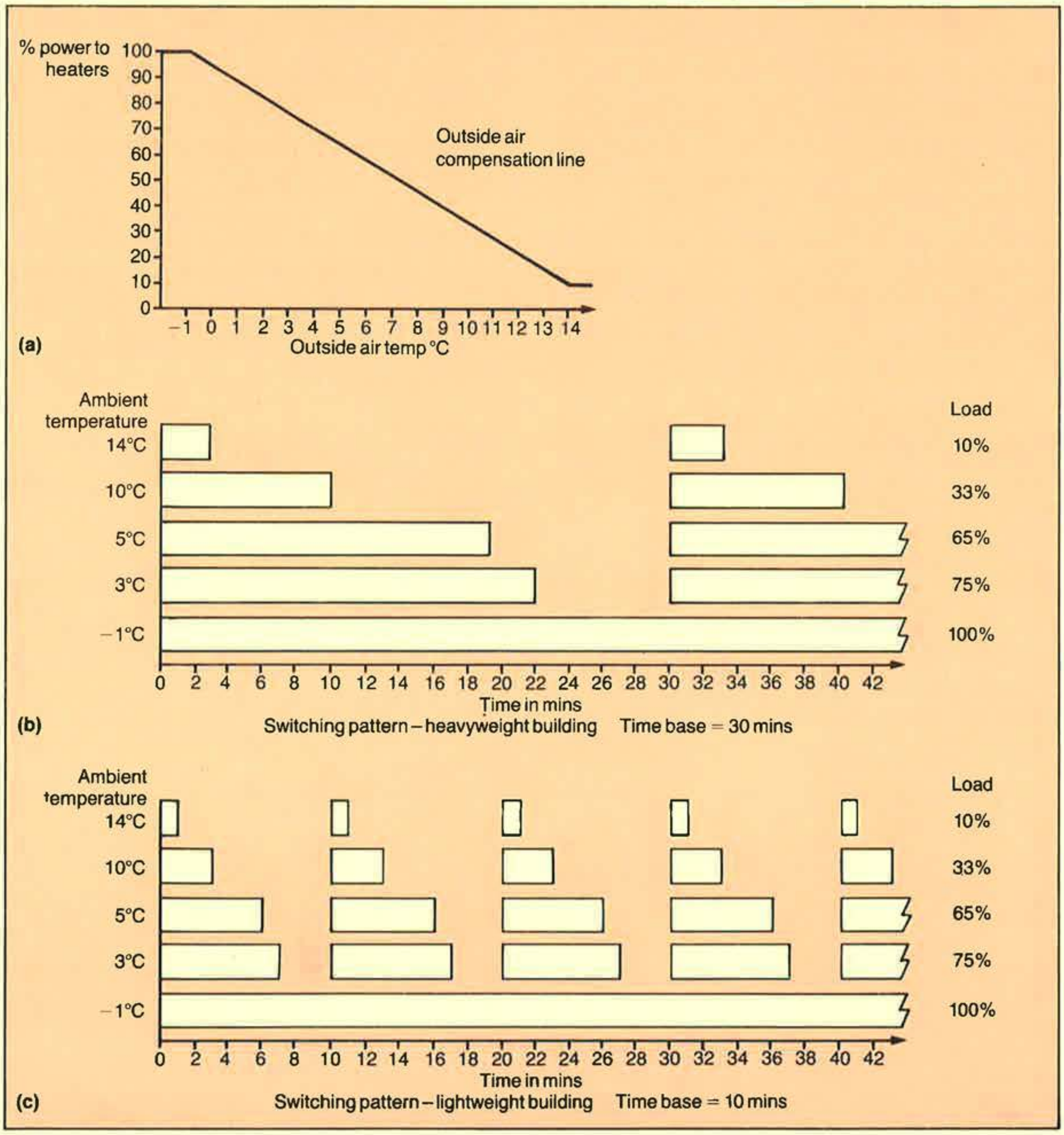

Fig 2. *Load cycling using microprocessor controller*

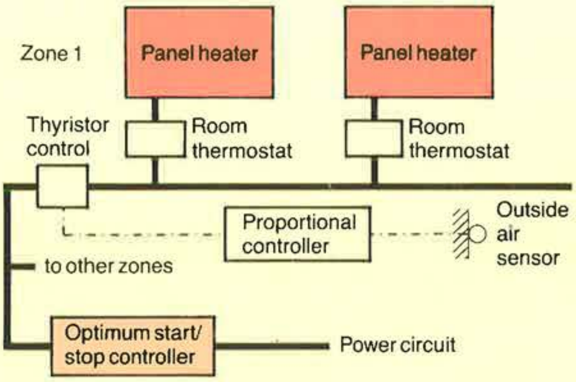

Fig 3. *Thyristor control – wiring layout*

The arrangement is shown in Figure 3. This schematic shows the requirement for single zone control. The thyristor is driven by a proportional controller, the signal from which is determined from a preset schedule with outside air temperature as shown by Figure 4.

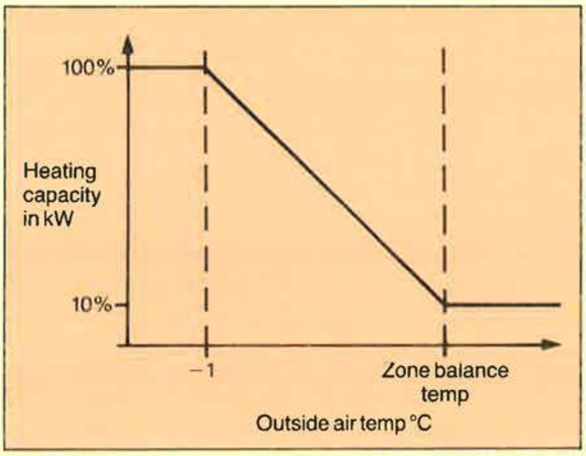

Fig 4. *Proportional band for thyristor control*

The proportional band of the controller would be set to match the characteristics of the room. At design ambient temperature the proportional controller signal would be at a maximum and at the balance temperature the signal would be a minimum eg 10%. The balance temperature is that temperature at which the building heat loss is equivalent to the casual heat gains, when the net heat loss is zero.

The thyristor would use the 'burst firing' technique for modulating power to the panel heaters. With this technique the control system delivers bursts or groups of complete supply cycles to the load to minimise interference to the supply.

As the heating load reduces the off time would increase, conversely as the load increases beyond 50%, the on time would increase.

*(iii) Decentralised control of maximum heating demand*
It is also feasible to use a microprocessor based controller that is installed on an individual heater and is able to control a number of additional 'slave' heaters within the same room. It provides the basic control functions of temperature control, time clock, optimum start, and frost protection. The controller also restricts the heaters' output when room temperature falls rapidly, as would be the case when windows were opened. The output from the heater is maintained at the capacity in use immediately prior to the window opening. To cope with the slower changes in heat requirement brought about by changes in external temperature, the heat output is allowed to rise at an additional 15% per hour thereafter.

If the occupant opens the window to reduce the air temperature, there would be a rapid decay in the room temperature with the panel heater being activated as the room thermostat switching differential is reached. The load released by the controller would then correspond to that used prior to the thermostat switching. As long as the windows remain open the heaters have insufficient capacity to restore the room temperature to the thermostat set point. The room therefore cools down until the occupant closes the window, at which time the temperature can be restored in the space.

The heating supply is switched by a triac system on a one minute time base, such that at 50% load the supply would be on for 30 seconds and off for 30 seconds. This switching pattern is similar to that shown in Figure 2(c), with a shorter time base.

The controller can set its switching pattern on the basis of the previous day's average heating energy demand with an additional 20% capacity if required. In this way the building maximum demands would be limited to the heating requirement dictated by the previous day's average demand plus a tolerance of 20% if required.

The controller provides this range of control functions on a decentralised basis. The capital cost of the controller would double the cost of the panel heater. However if there are several open plan areas within the building that could employ a single master controller to drive a number of slave units in each zone, capital costs would be reduced. On smaller installations, also, the decentralised controller may prove a cheaper solution than the central microprocessor control or proportional thyristor control.

## Hot water service

In EED new build offices or major refurbishments the opportunity should be taken to provide decentralised Hot Water Service (HWS) for handwashing.

The fact that hot water is used infrequently and in small quantities in such buildings means that a centralised system would incur considerable distribution losses relative to the amount of water actually used. A fossil fuel boiler would be even more inefficient because it would incur primary circulation and combustion losses as well.

The design procedure for decentralised HWS is described in Technical Information – *Hot water service in offices* – EC 4181. This also deals in outline with the design of larger scale uses of hot water such as for catering within office buildings.

Decentralised electric HWS lends itself to submetering within the building when multiple tenants are in occupation so that the washrooms within each sublet area can be charged separately.

## Further options

To allow closer supervision of the heating system by the building operator and to improve comfort in summer, the following options may be considered:

**(1) Building energy management system**

As an option, an integrated building energy management system could be installed to deal with the following functions:

a) Monitoring of temperatures actually maintained in each zone.

b) Submetering of energy supplied to each zone where subletting is taking place.

c) Profiling of heat availability to different zones to suit different occupation patterns.

d) Control of other building services, eg lifts.

e) Security.

f) Logging of plant use and thermal conditions to prompt maintenance scheduling.

**(2) Exposed soffits**

Although false ceilings may be included for cosmetic reasons, consideration should be given to omitting them or redesigning them as slatted ceilings to expose the soffit.

This will increase the building response factor.

It will then be easier to control conditions by dampening temperature swings caused by heat gains; it will be particularly useful to reduce the effects of solar gains when overheating might otherwise occur. Omission of the false ceiling has implications for the lighting design which will have to be resolved and costed alongside the capital saving. For instance, the use of uplighters would avoid the need to conceal wiring at ceiling level. Nevertheless the temperature control benefits outside the heating season can make it worthwhile considering extra effort at the design stage.

## Cost effectiveness

A cost effectiveness calculation must be carried out to check the viability of the scheme proposed, for instance compared with an alternative using Building Regulations standard insulation and fossil fuel fired boilers. Technical Information – *Financial Appraisals* – EC 4972 explains the procedure.

**ECMD Contact:** A.J. Johnson B.Eng.MCIBSE