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The Performance and Selection of Domestic Heaters

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The thermal performance of a wide range of domestic heaters has been assessed from detailed measurements of the thermal distribution patterns from the heaters installed in typical houses. Heated floors and ducted systems provide satisfactory temperature distributions but convection "space" heaters distribute the heat relatively poorly.

Comparison of the cost of operating heaters in Melbourne, Australia with various fuels shows that gas, resistive storage heating with off-peak electricity, and heat pumps using electricity at normal tariffs, may be operated at comparable rates. The operating costs are more than double if the fuel is oil, bottled gas or electricity at normal tariffs for systems other than heat pumps.

The factors to be considered when selecting a heating system for a particular dwelling are discussed.

Introduction

In recent years there has been an increasing desire for greater thermal comfort in the average suburban dwelling, and this has led to the development by manufacturers of a large range of domestic heating units powered mainly by gas, oil and electricity.

The general assessment of these heaters in terms of the "thermal comfort" of the occupants of a particular house is difficult since "thermal comfort" is related not only to such physical factors as air temperature, radiant temperature, temperature gradients, air velocities within the room (natural draughts and forced air circulation) and humidity, but is also dependent on such factors as the clothing, physical activity and the individual physiological processes of the occupants (Ref.1).

The achievement of a favourable thermal environment will also involve other factors such as the climatic conditions outside the building, which are usually a function of its geographical location [the relative heating requirements for different locations may be assessed by means of the degree day concept (Ref.2)], the type of construction of the building (cavity double brick, brick-veneer, timber, etc.), and the degree of thermal insulation.

The choice of a heater should be made by the householder on the basis of reputed thermal performance, the intended usage pattern, the availability of suitable fuels and the cost of installing and operating a unit.

Thermal performance data are usually restricted to the thermal output (kW, Btu/h) and are seldom correlated with the distribution of the heat within a room or dwelling. However, although a correctly sized heater will produce an adequate mean temperature within a room, the occupants may still feel uncomfortable since with some types of heaters there is a relatively high temperature gradient between the floor and ceiling. If sufficiently severe these gradients may lead to a feeling of cold feet, stuffiness or both (Ref.3). Thus, the distribution of the heating should be considered in conjunction with thermal output when assessing the thermal performance of a heater.

The life style of the intending users strongly influences the selection of a heater, since it will determine whether the whole or only part of the house is to be heated and whether continuous or intermittent heating is required.

The selection of the fuel for the heating device is important since an otherwise satisfactory heater would be a poor choice if the supplies of fuel it consumes were uncertain or inordinately expensive.

The installed cost and the operating costs are major determinants affecting the choice of home heating systems. The former varies from a few dollars for a simple portable heater, which would provide localized thermal comfort, to several thousand dollars for a complete reticulated system providing controlled heating to a whole house. Operating costs, which will be dependent to some extent on the fuel used, are even more important since over the lifetime of the heater the extra cost of operating some systems may completely outweigh any initial savings in the capital and installation costs of the system.

The purpose of the present work was three-fold: firstly, to establish how effectively the various heating systems currently used in dwellings distribute the heat; secondly, to discuss the relative cost of operating heaters using different fuels; and thirdly, to provide some guidelines which will assist potential installers of heating systems in the selection of a system most suited to their particular requirements.

Although information on the latter two topics may be obtained from various sources, relatively little is available on the performance of heaters, particularly that relating to the temperature distributions produced by various kinds of heaters.

The results of a study of the temperature distribution produced by a wide range of heaters installed in typical dwellings are presented in Section 2.

The relative costs of operating heating systems on different fuels, based on fuel costs current in Melbourne, Australia on 1 January 1980 are given in Section 3.

The major aspects to be considered when selecting a heater are summarized in Section 4.

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Temperature Distributions

General

A brief summary of the main types of heaters in general use is given in Table 1. The heating systems investigated included gas, oil and electrical convection heaters with natural and forced air circulation, ducted systems, electrically heated ceilings, water and electrically heated concrete slab-on-ground floors and under-carpet heated floors. Most measurements were made on heaters installed in established houses and the heaters were operated in the normal manner of the householder. Measurements were in general restricted to single rooms and in all cases the ceilings were insulated. The work was carried out in Melbourne during the months of May, June and July 1977 and June, July and August 1978.

Experimental

The temperature distribution through a vertical section of a room (usually coinciding with a major axis) was determined by recording the thermo-emfs from a set of approximately 30 thermocouples, mounted on a vertical pole at 100 mm centres between floor and ceiling, as the pole was moved in steps of 100-400 mm along the chosen axis. The thermo-emfs were measured and recorded with a DIGITREND Model 220 Data Logger which automatically converted the millivolt readings to degrees Celsius and provided a paper print-out. From the recorded data (approximately 800-1000 points per section) isotherms were drawn either by manual means or by utilizing the CSIRO Cyber computer. A record was also made of outside temperature, approximate temperature of the air issuing from convection heaters, floor and ceiling temperatures and the globe temperature approximately one metre above floor level. Approximate air velocities from convection-type heaters were determined with a hand-held Lambrecht 100 mm vane anemometer.

Results

Plotted isotherms which depict the temperature distribution in a cross-section of the heated room were determined for most of the heaters listed in Table 1. Isotherms for representative cases are shown in Figures 1 to 8. Floor and ceiling temperatures were different from the air temperature 25 mm away from the respective surface by 1-4 K. The isotherms, which related to the air temperature, have therefore been terminated 25 mm away from both the floor and the ceiling.

For most fan-assisted convection heaters, cold air enters at or near the floor and the hot air is discharged downwards at about 0.6 m above floor level. The temperature of the hot air depends on the setting of the controls but is frequently in the range 70°-100°C. This type of heater is the more modern version of similar heaters described by Muncey and Bautovich (Ref.4). The temperature distribution for an oil fuel space heater is shown in Figure 1 and indicates that within a metre of the heater the emerging jet of hot air has changed direction and flows towards the ceiling, where it produces a layer of hot air. At distances beyond a metre from the heater there tends to be a fairly uniform temperature gradient between 25 mm above floor level and 25 mm below ceiling level of up to 10-12 K in 2.5 m. Other heaters in this general category have similar characteristics to those in Figure 1 but with individual variants. For the particular gas heater examined there was a region in front of the fire extending to some 1.5 to 2 m radius where the effects of radiant heat from the unit were appreciable. This advantage over the oil heater was offset to some extent by the more rapid rise of heated air from this unit due to the relatively low velocity of the air output.

The output of heated air from the gas wall furnace was higher above the floor than that from gas or the oil space heaters at a much lower velocity, more diffuse, but still at a comparable temperature (66°C). Consequently the stream of hot air rose to the ceiling in closer proximity to the unit, but within most of the room a fairly uniform temperature gradient of magnitude comparable to that from the oil heater was set up between the floor and ceiling.

The electric heat bank discharged hot air at a temperature of approximately 80°C at about 100 mm above the floor level. The air velocity was low and again this hot air rose rapidly to the ceiling and produced stratification in most of the room similar to, but more marked than, that from the oil heater.

The temperature distribution and the temperature gradients obtained for a hot-water, fan-assisted system were essentially the same as those obtained with the oil heater.

Small portable electric fan heaters mounted at floor level were found to have temperature distributions similar in general features to those from the larger built-in space heaters but the temperature gradients between floor and ceiling were rather less.

The electric wall furnace examined had the hot air exit at floor level and the option of the air inlet either 1.8 m or 0.7 m from the floor. Figure 2 indicates that heat from this heater was carried several metres into the room at a relatively low level before the heated air rose towards the ceiling. At distances beyond two to three metres, the normal stratification pattern emerges.

For distances closer than 2 m, the temperatures below 500 mm above floor level are above 30°C, and above 500 mm the isotherms tend to become vertical, indicating that there is only a slight temperature gradient between 500 mm above floor level and the ceiling. The temperature distribution for the heater operating with the lower air inlet was marginally better than that obtained when operating with the higher air inlet.

The ducted heating systems examined were designed for whole house heating. They differed from the room convection heaters discussed above in that the heated air entered through registers either at floor or ceiling level within the rooms and the cold air returned to the heating device at a

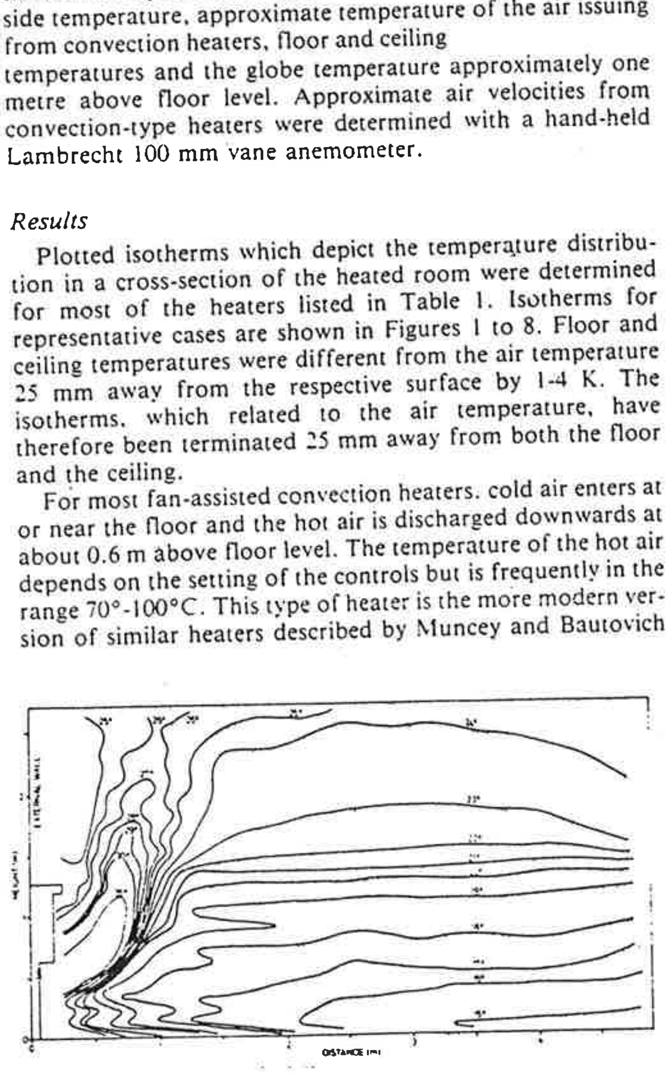

Fig. 1. Distribution of temperatures with oil space heater. Isotherms at 1 and 5 K intervals. Outside temp. 6°C. Outlet air temp. 70°C. Outlet air velocity 1.25 m/s.

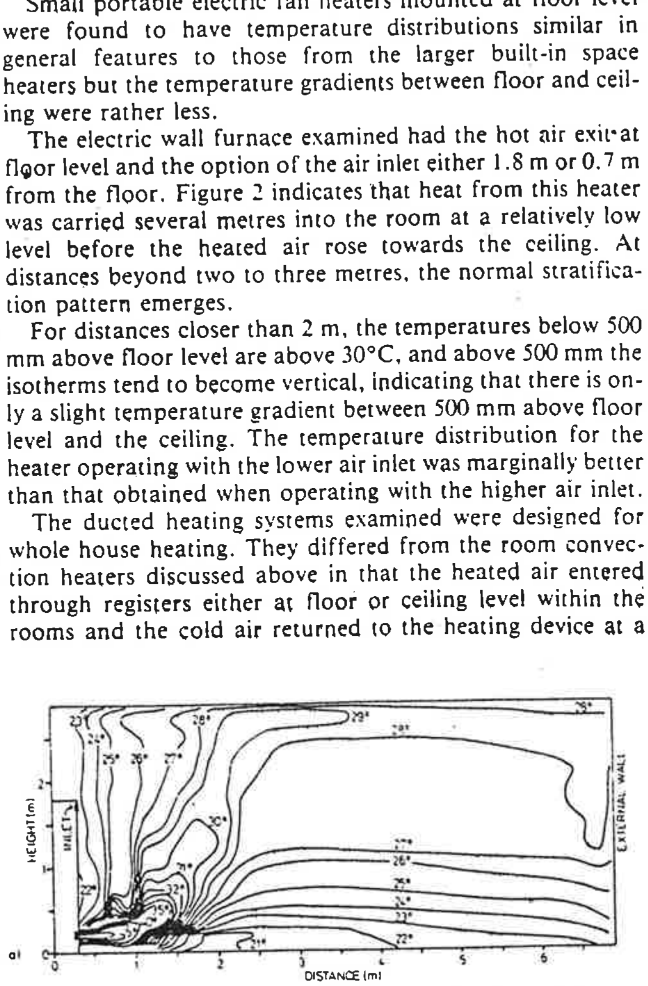

Fig. 2. Distribution of temperatures with electric wall furnace. Isotherms at 1 and 5 K intervals. Outside temp. 8°C. Outlet air temp. 80°C. Outlet air velocity 2.2 m/s.

point remote from the entry registers outside the main heated rooms. In one system the heated air issued from floor registers at a temperature of approximately 45°C and velocity about 2.2 m/s. The air was deflected on emerging from the duct so that the main stream was at an appreciable angle to the vertical and in a direction normal to the plane of measurement. The ensuing temperature distribution (Fig.3) indicated that the temperature gradient from floor to ceiling was 4 K over 3 m. In a second system, the heated air issued into the rooms from ceiling registers at temperatures between 30 and 40°C. The velocity of the air varied in the range 0.8 to 2.2 m/s from register to register. The observed temperature distribution (Fig.4) is markedly different from that of the floor register system.

Convection heaters which do not have a fan to assist the air circulation produced temperature distributions similar to that shown in Figure 5. Above the heater there is a relatively narrow stream of warm air which rises towards the ceiling at a velocity of about 0.2 m/s. Some of these heaters had a region in front of them which was significantly influenced by radiation from the heater. Temperature differences between floor and ceiling of a few degrees were common in most of the room, and the heating was well distributed throughout the room.

There are several types of heaters which transfer heat mainly by radiation or a combination of radiation and convection. Heaters with a relatively small, high-temperature source constitute one type and include gas fires, bar radiators and open fires. The temperature distribution for a gas fire of the type commonly used some 20-30 years ago was determined and is shown in Figure 6. Although the temperatures measured here are due to the combined effects of air temperature and radiation, it is clear that the influence of the heating was mainly within a region some two metres in radius and one metre high and rapidly decreased with increasing distance from the heater. Another type of radiant heater consists of a relatively low-temperature source of extended area; examples of this type include the various floor and ceiling heating systems. The temperature distribution from an electric ceiling heater was measured and this is given in Figure 7. Although there were high temperature gradients close to the ceiling only 2-3 K difference in temperature was measured between floor level and 300 mm below the ceiling, and the heating was found to be uniformly distributed throughout the room. Floors heated either electrically (resistance elements embedded in concrete or installed between floor and carpet) or hydronically (hot water pipes embedded in concrete) produced temperature distributions where the temperature at the surface of the floor was some 5 K higher than the air temperature just above and essentially no variation from just above floor level to just below ceiling level. In some cases the temperature of the room increased by approximately 2 K from the region near external walls to the central region of the room (Fig.8).

Discussion of temperature distributions

Although external temperatures and other climatic factors varied during the course of these experiments, and house plans differed considerably, we believe that the general temperature patterns obtained for the different heaters may be regarded as typical.

The patterns that emerged for rooms having *heated concrete floor slabs or under-carpet heating* showed that there was an excellent distribution of heat throughout the rooms, minimal temperature gradients, the floor temperatures were a few degrees above the mean room temperatures and the rooms were essentially free from draughts. The occupants of such rooms should enjoy a high degree of thermal comfort.

A similar degree of comfort should be experienced by occupants of rooms with *heated ceilings* because although there were marked temperature gradients close to the ceiling there was little gradation elsewhere throughout the rooms.

Of the convection heaters examined *ducted systems* gave the best distribution of heat due to the multi-point distribution of the heated air, the remote location of the return air register, the relatively low temperature of the air discharged from the ducts and adequate air circulation. Systems using floor registers were significantly better than those with ceiling registers and gave a temperature difference of about 4 K between floor and ceiling and proportionally less over the height of the occupants. Gradients of this magnitude should not cause any feeling of discomfort. With ceiling register systems there were relatively large temperature gradients in the upper levels of the room but acceptable gradients between floor and head height. To achieve these acceptable gradients it is essential that the return-air register be located near floor level.

Convection heaters of the *space heater* type including fan-assisted water panel heaters all produced a higher degree of stratification than ducted systems with floor registers. The heat patterns were characterized by a region of relatively high temperature associated with the emergent air stream and elsewhere by a vertically stratified distribution pattern. The patterns from some heaters had superimposed on them the

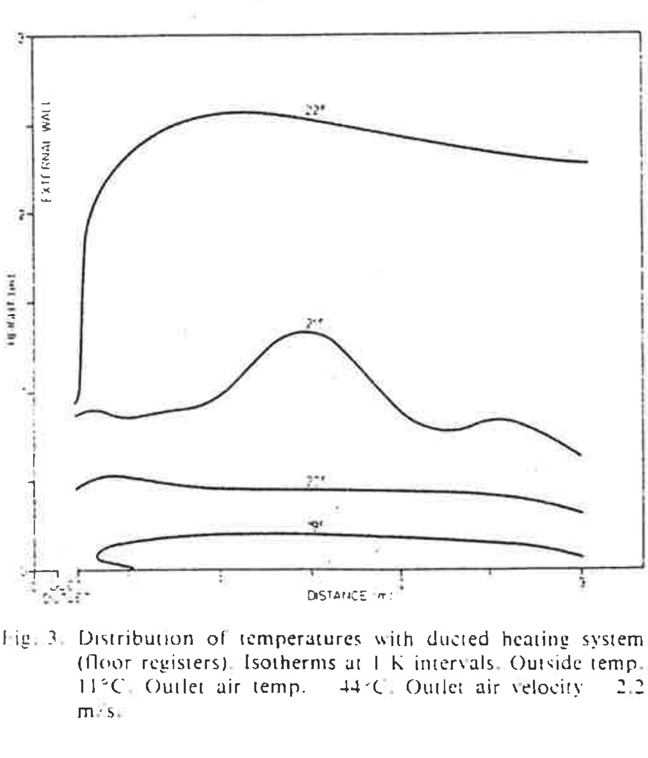

Fig. 3. Distribution of temperatures with ducted heating system (floor registers). Isotherms at 1 K intervals. Outside temp. 11°C. Outlet air temp. 44°C. Outlet air velocity 2.2 m/s.

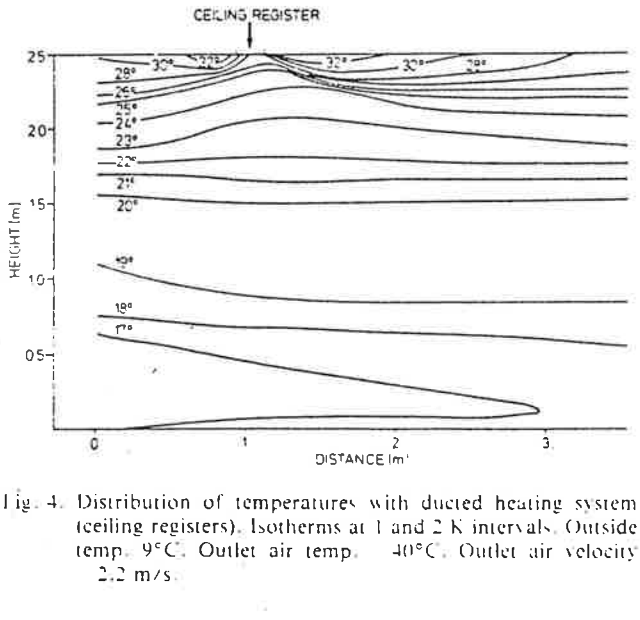

Fig. 4. Distribution of temperatures with ducted heating system (ceiling registers). Isotherms at 1 and 2 K intervals. Outside temp. 9°C. Outlet air temp. 40°C. Outlet air velocity 2.2 m/s.

effects of radiant heating in the region immediately in front of the heater. For best performance these units should have an air circulation rate such that the temperature of the air leaving the heater does not exceed 25 K above room temperature. The heated air stream should emerge at or near floor level with sufficient velocity to carry it well into the room but not so great that there is too rapid a movement of air past the occupants (Ref.5). The cooler air should return to the heater at least 0.7 m above floor level. Few, if any, gas or oil powered units have these characteristics and consequently temperatures difference of 8-10 K between floor and ceiling were common. Thus, in rooms heated by these methods, it is to be expected that there will be locations within the room where the occupants will be conscious of inadequate heating near the floor and, because of the high temperature gradient, a sensation of excessive temperature at the level of the head. Electric space heaters including the small portable varieties usually incorporated at least some of the desirable design features and consequently gave somewhat better temperature distributions.

Heaters circulating air by *natural convection* (i.e. without fan assistance) such as oil or water-filled panel heaters produced a stream of warmed air which rose almost vertically. In the case of heaters mounted on walls under windows this air stream counteracts the cold downstream associated with the window. Within the major part of the room relatively small temperature gradients were measured and the heating was well distributed throughout the room.

Radiant heaters of the relatively small, high-temperature type, such as gas fires, electric bar radiators and open fires produced a directional form of heating which should provide adequate thermal comfort, for seated occupants, in a limited zone around the heater.

Fuels and Operating Costs

Gas, oil and electricity are the main sources of energy used for heating although wood and briquettes are still used in some cases. The selection of a suitable energy source depends on its availability, the relative cost of the various fuels for the particular system adopted and the mode of operation of this system (e.g. continuous or intermittent, whole or part house heating).

The amount of fuel energy required per annum depends on the climatic conditions, the size and type of house, its insulation and the mode of operation of the heating system. The cost of the various fuels will vary considerably depending on the location of the dwelling. It is not feasible to detail here a cost comparison for every location within Australia but as a guide, an analysis of the cost of heating by various sources as a function of heating load has been carried out for Melbourne, Australia. A similar analysis may readily be undertaken for any location given the cost of fuel pertaining to that region.

As a guide to the heating energy required, calculations of the heating load for a typical brick-veneer house with tiled roof and insulated ceiling (50 mm mineral wool batts) and suspended floor located in Melbourne suggest that about 50 GJ of heating energy per annum will be required to maintain comfort conditions throughout the 8 months of the heating season. (Ref.6).

The annual operating costs as a function of heating load are plotted in Figure 9 for gas, oil and electricity. The tariffs used are those applicable on 1 January 1980 in Melbourne, Australia. The gas tariff (03) shown is the lowest available and applies to dwellings fitted with gas space heaters. The operating cost shown in Figure 9 does not include a supply charge of $40.20 per annum. This will however be offset to some extent, in homes having other gas appliances, by savings in the cost of gas used for non-space heating purposes. The tariff for oil is based on a price of 20.82 c/L and a calorific value of 37.6 MJ/L. In some situations oil and piped gas are unavailable and bottled gas (LP gas) may be used as the source of heating energy. The cost of LP gas varies depending on the location. The costs shown are based on a gas price of $17.10 per 45 kg cylinder. To this must be added an annual rental of $8 per cylinder. The calorific value has been taken as 50.4 MJ/kg. Three electricity tariffs are available: GB is the basic domestic tariff, GC is a reduced domestic tariff available to consumers having a permanently wired cooking range, hot water service and electric refrigerator, J applies to off-peak storage heating systems. In the case of tariffs GB and GC it has been assumed that the first 1944 MJ per quarter is used for lighting and household appliances, so that all the heating is at the lowest rate. Likewise it has been assumed that the first 4320 MJ per quarter of tariff J is used for the hot water service.

The efficiency of gas and oil space heaters has been taken to be 60% but this may vary somewhat depending on the size of the unit and the heat setting. An efficiency of 100% has been assumed for electric resistance heating using tariffs GB and GC, whereas an efficiency of 90% has been assumed for off-peak heating using tariff J to allow for loss of heat from the store during periods when heating is not required. An efficiency of 200% (coefficient of performance of 2) has been assumed for heat pump air-conditioning systems. This figure is an average value since smaller reverse cycle window-type units may have efficiencies as low as 150% whereas for the larger heat pumps the efficiencies may reach 300%. However, the efficiency of heat pumps is a function of the outside climatic conditions and decreases markedly when the outside temperature falls below 5°C.

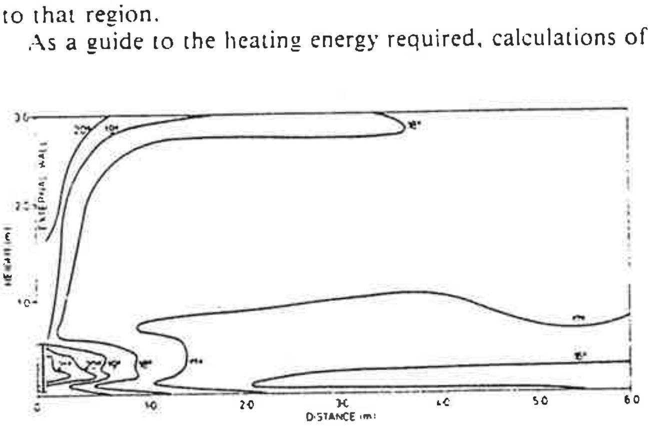

Fig. 5 Distribution of temperatures with hot-water panel heaters. Isotherms at 1 K intervals. Outside temp. 9°C.

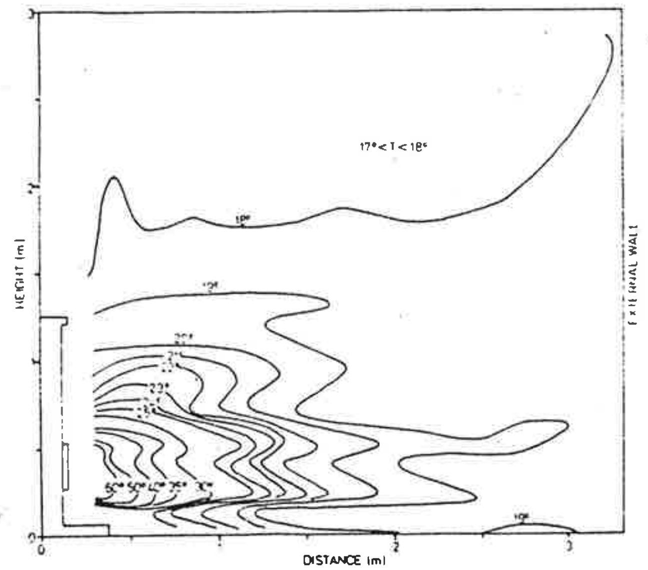

Fig. 6 Distribution of temperatures with radiant gas fire Isotherms at 1, 5 and 10 K intervals. Outside temp. 9°C.

Selection of a Heating System

There is no single heater or heating system which will best satisfy the heating requirements of all householders and their families; each case should be considered on its merits.

In selecting a heater or heating system for a given situation the following factors should be carefully considered:

1) whole or part house heating, or personal heating
2) continuous or intermittent heating
3) the heat load and size of heater required (Ref.7)
4) availability of energy sources
5) feasibility of installation — some systems cannot readily be installed in existing houses and there are often constraints which limit the choice of heaters for a particular house
6) capital and installation costs (may be dependent on point (5))
7) annual cost of fuel energy (dependent on fuel and heating system selected, Fig.9)
8) maintenance requirements and cost
9) how well the heating system in question distributes the heat, and in general, meets the present and possible future requirements of the household.

The above guidelines for the selection of a heater are very brief and there are a number of other points that should be specially mentioned.

Thermostatically controlled heaters are preferable to unregulated units since they match the supply of heat to the demand and thus provide thermal comfort at minimum cost.

Where electricity is the only source of energy available for heating, and appreciable house heating is required, it is clear from Figure 9 that a considerable saving in operating costs may be achieved by using either an off-peak storage system (tariff J) or a heat pump of either the reverse cycle variety or of the type designed specifically for heating. Although the capital costs involved in the latter systems may be considerably greater than that for the simpler resistive heaters the savings in the cost of energy may offset this within a few years and in the case of reverse cycle units, cooling during the summer months is available as a bonus.

Off-peak storage systems, particularly the free emission type (i.e. without a fan as exemplified by heated concrete floor slabs or "midi banks") are slow in thermal response and some care needs to be exercised in operating these systems to ensure that adequate heating is available when required and that overheating does not take place during mild periods which occasionally occur during the heating season. It is preferable to underheat with these systems and provide supplementary heating as required.

Floor coverings are important with slab heating. They should preferably have a low thermal resistance, e.g. ceramic

Heater	Mode of heating	Source of heating energy	Comments
Bar and rod type radiators	Radiation	Electricity	Portable or wall mounted
Oil filled panel heaters	Mainly convection	"	
Hot water panel heaters (wall mounted)	Mainly convection, may be fan assisted	Oil or gas (sometimes electricity)	Water circulated by thermostatically controlled pump.
Floor slab heating			
(a) embedded electric heating elements	Radiation and convection	Off-peak* electricity	
(b) hot-water through pipes embedded in slab		Usually oil or gas	Water circulated by thermostatically controlled pump.
Under-floor carpet heating	Radiation and convection	Electricity	Heating element situated beneath carpet but insulated from floor.
Ceiling heating	Radiation	Electricity	Electric heating element either embedded in or situated immediately above the ceiling lining.
Electric storage heater, heavily insulated ("heat bank")	Mainly convection, fan assisted	Off-peak electricity	Heat output thermostatically controlled.
Electric storage heater ("midi bank")	Radiation and convection, no fan	Off-peak electricity	Free emission device.
Electric fan heater (portable)	Convection	Electricity	Usually 2 or 3 heat outputs available. Some are thermostatically controlled.
Room space heaters	Some radiation but mainly fan assisted convection	Gas, oil and electricity	Some units thermostatically controlled. May heat 2-3 rooms.
Ducted heating systems	Convection, fan assisted	Gas, oil and electricity	Most units enable part or all of the house to be heated.
Ducted heating system using heat pumps	Convection, fan assisted	Electricity	Heat output 2-3 times electrical power input.
Reverse cycle room air conditioners	Convection	Electricity	Heat output 1.5-2 times electrical power input.

Table 1: Types of heaters in Australian dwellings.

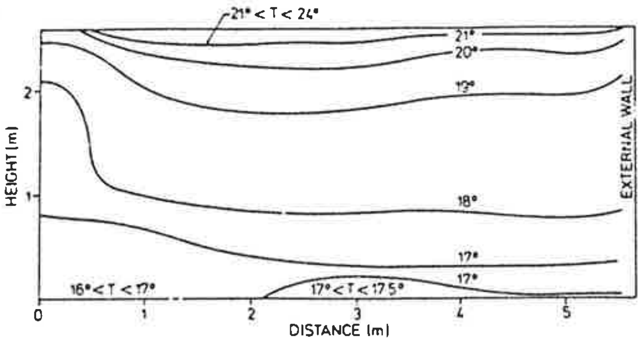

Fig. 7. Distribution of temperatures with electrically heated ceiling. Isotherms at 1 K intervals. Outside temp. 12°C.

or thin vinyl tiles. However if carpet is to be used it should not be too thick.

Ducts under concrete slabs-on-ground are not currently recommended since problems have occured from the high humidity which develops within the house should ingress of water into these ducts occur.

Noise is an important consideration, and although it is minimal with most ducted systems (particularly if the furnace is located externally) and space heaters, the noise level associated with the simpler reverse cycle air conditioners may be unacceptable in some circumstances to some users.

Due consideration should be given to the final appearance of the system to ensure that it is compatible with existing decor.

Discussion and Conclusions

From the study of the distribution of temperature it would appear that:

1. Slab floor heating systems produce an almost ideal distribution of heating within dwellings. Some problems with overheating may occur.
2. Well designed ducted heating systems give satisfactory distribution of the heating. Temperature distributions with systems using floor outlet registers are more uniform than those from systems with overhead registers although the latter distributions are acceptable.
3. Most convection "space" heaters give relatively poor distribution of the heating because:
   (a) the temperature of the outlet air is too high,
   (b) the velocity of the outlet air is too low,
   (c) the heated air in gas and oil fired units is usually discharged at a relatively high level rather than at floor level.

   These factors can only be rectified by the manufacturers of such units incorporating suitable changes in design. Whilst most convection "space" heaters produce regions of thermal comfort it is almost inevitable that there will be some regions in the room where the occupants will experience discomfort from cold feet or stuffiness.
4. Multi-point distribution of the heating is necessary in large rooms if uniform heating is to be achieved.
5. Many small portable heaters (both radiant and convection) provide regions of adequate thermal comfort, particularly in small rooms, at relatively low capital cost.

From the relatively simple study of the operating costs of heaters using different fuels, graphically summarized in Figure 9, it is apparent that gas, where available, is a relatively cheap fuel. Gas heating is readily applicable to new and existing dwellings. Normally locations without ready access to piped gas services do not lend themselves to gas heating, but bottled LP gas is available at a premium (at least twice the price) and may provide a solution in special cases.

Storage systems using off-peak electricity may be operated at comparable rates to gas. Concrete slab heating employing embedded resistive elements is usually restricted to new constructions. Storage heaters (heat banks) do not have this restriction. Hydronic systems employing relatively large water storage and utilizing off-peak electricity may be adapted to existing as well as new dwellings, but the capital cost of these systems is relatively high.

Systems powered by heat pumps, particularly the larger units, should provide heating at an operating cost comparable to, or even less than, that of either gas or off-peak electricity. The main disadvantages of these systems are that the installation costs are relatively high, noise may be a problem with the smaller wall or window mounted units and the efficiency falls off with most units for outside temperatures below 5°C.

The escalation in the cost of heating oil and the possibility of shortages in the future do not encourage the choice of oil

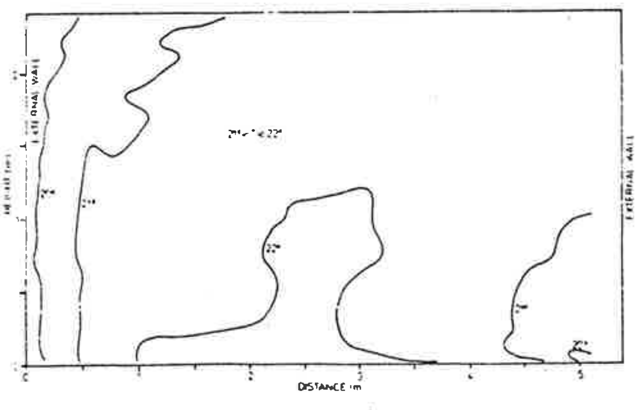

Fig. 8. Distribution of temperatures with electrically heated concrete floor. Isotherms at 1 K intervals. Outside temp. 12°C.

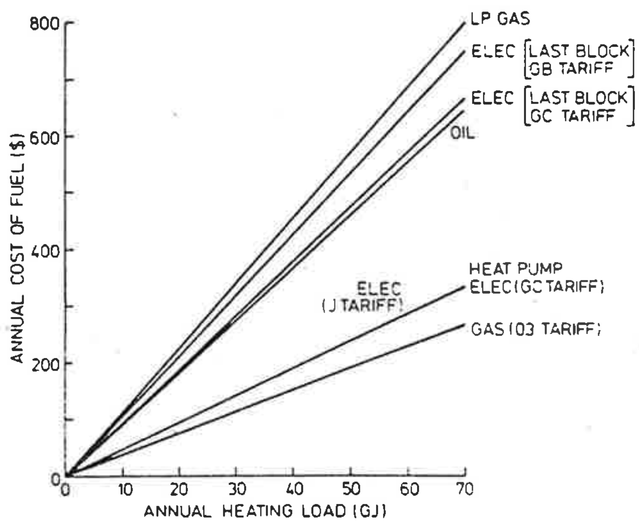

Fig. 9. Annual cost of fuel as a function of annual heating load. Melbourne, Australia, 1 January 1980.

Appliance efficiencies assumed:— gas and oil, 60%; electricity, GB and GC tariffs, resistance heating 100%, heat pump 200%; J tariff, 90%.

fired appliances for new installations. The cost of operating existing oil units, particularly if maintenance costs are included, is almost certainly as high as electrically powered heating units operating on tariff GC.

When selecting a heating system for a dwelling, each case must be decided on its merits with due consideration being given to the factors set out in Section 4. Some installations are expensive but offer attractive savings in operating costs and where the heating requirements are large the pay-back period may be quite short. In other cases the higher operating costs of a simple heater used only occasionally may be offset by the relatively small outlay in purchasing the unit.

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