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Technical Paper 14

Keeping warm in a cooler house

*Creating thermal comfort with background heating
and local supplementary warmth*



OXFORD
BROOKES
UNIVERSITY

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The views expressed in the research report(s), presented in this Historic Scotland Technical Paper, are those of the researchers and do not necessarily represent those of Historic Scotland.

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Introduction

Historic Scotland Technical Paper 14 forms one of a series of three reports, Technical Papers 12 to 14, that look at some of the wider issues concerning the existing built environment, and how it is altered to respond to current and emerging pressures regarding energy efficiency. These reports comment on topics that are often not fully investigated in the mainstream discussions on energy efficiency and the domestic housing stock. The topics are: Indoor air quality and older structures (What is the balance with factors such as ventilation and health?), embodied energy (The wider energy costs associated with our choices of materials used in upgrade work, and are they as durable and long lasting as the elements they replaced?), and the topic of this paper that looks at energy efficiency and thermal comfort (How do we achieve thermal comfort in older homes, and are there ways of making provision for it that are better than the existing conventional systems?).

A home fulfils many functions, but probably a function high on any list is comfort. That means, is it warm and pleasant to live in? Comfort is a subjective judgement, and it appears that there has become a dominant criterion of comfort that does not suit many and is expensive to achieve in all but the most heavily insulated buildings. Our view on what the thermal envelope is and how it performs needs development, especially as it appears that the way we heat buildings now is very different from how it was done historically, and in a way that suits the occupants and the building. This must of course be more than modish re-creation. There is also potential to challenge conventional wisdom on how to make provision for thermal comfort, potentially to improve health and reduce the amount of energy needed to keep traditional buildings comfortable. Many of the ideas discussed in this paper are results from a previous spike in energy prices, but they remain as relevant for discussion as they were in the 1970s.

Some of the themes overlap in the series, and this is deliberate, for in discussion of upgrade options many factors come into play, and in complex systems boundaries are sometimes fluid. The views expressed in these reports are those of the authors, and not necessarily those of Historic Scotland or the Scottish Government.

Research report

Keeping warm in a cooler house

*Creating thermal comfort with background heating
and local supplementary warmth*

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September 2011

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Executive summary

This report challenges the perception that houses must be heated to modern standards, and explores achieving comfort in an older house using background low-temperature heating and local supplementary heaters to create warmth as required. The report neither advocates that buildings be not heated, nor that they be heated to inappropriate levels. Living in a cool house – that is, a house cooler than generally expected today – might sound unacceptable, but was commonplace until relatively recently and is comfortable if human behaviour is adjusted accordingly.

Using background heating and local supplementary warmth as a heating strategy does not attempt to provide a uniform indoor temperature, but creates thermal microclimates when and where required, in a system in which occupants adapt both their building and themselves to stay comfortable. The report proposes that the interior be maintained at a background temperature of 16°C and appropriate local supplementary heat-sources be provided, when and where desired, usually in the form of a radiant heater. The report demonstrates that with this heating strategy it is possible to provide comfortable conditions while significantly lowering energy costs and related CO₂ emissions.

The report focuses on residential properties, particularly those constructed before 1919 using traditional building materials and construction techniques although the principles can also be applied to more recently built dwellings of a similar type.

The report discusses the ideas behind the proposed heating strategy, appliances that may be appropriate for providing warmth, associated comfort and health issues, and the importance of adopting suitable clothing. It examines the strategy's energy-use benefits and how it relates to current temperature standards.

Although the proposed heating strategy cannot reduce the energy consumption to the levels expected of newly built houses with modern standards of insulation, it can be used together with other technical upgrade measures. It seems that, on balance, the suggested environments would be better for the health of the occupants than those often used today.

The report recommends exploring energy savings further by the thermal simulation of a selection of traditional houses; identifying, and developing further, suitable radiant appliances, including their control methods; and developing guidance to residents.

The report also shows that houses – and traditional houses in particular – are ill-served by the existing standards for thermal comfort and that there is a need for a new standard, or guideline, specifically for the indoor environment in houses (and other buildings with variable indoor environments).

Creating thermal comfort with background heating and local supplementary warmth should more often be considered as a heating strategy, instead of relying only on technical upgrades of the building fabric and services; indeed, it can easily complement such upgrades and achieve even better savings.

1. Introduction

Heating older houses can require more energy than heating newly built houses with modern standards of insulation, and is therefore more costly. How to upgrade older houses to make them more energy and cost efficient is, nowadays, a much discussed topic. An option not so often discussed is to save energy and costs by reducing the expected heating levels. This might sound unacceptable. However, living in a cool house – that is, a house cooler than generally expected today – was not only commonplace until relatively recently, but is comfortable if human behaviour is adjusted accordingly.

In this report we challenge the perception that houses must be heated to modern standards, and explore achieving comfort in an older house using background low-temperature heating and local supplementary heaters to create warmth as required. This heating strategy does not attempt to provide a uniform indoor temperature, but creates thermal microclimates when and where required, in a system in which occupants adapt both their building and themselves to stay comfortable. This approach is often referred to as the adaptive thermal comfort model ([Nicol et al., in press](#)).

It is worth pointing out that we are neither advocating that buildings be not heated, nor that they be heated to inappropriate levels. Rather we show that, in conjunction with other energy saving measures, it is possible to provide comfortable conditions while significantly lowering energy costs and related carbon dioxide (CO₂) emissions, providing comfort by using lower background-temperature heating and local warmth from supplementary heaters.

The following report focuses on residential properties, such as houses and flats, but the approaches described may also, where appropriate, apply to other uses of traditional buildings, such as for offices, sports facilities or workshops.

Older houses here mean those constructed before 1919, using traditional building materials and construction techniques, although the principles can also be applied to more recently built dwellings of a similar type. These buildings are therefore often referred to as traditional buildings.

This report starts with a general introduction to heating strategies ([Section 2](#)) before describing in more detail the ideas behind the particular strategy of using background heating with local supplementary heaters to provide warmth ([Section 3](#)). We then discuss the appliances that may be appropriate for providing this warmth ([Section 4](#)), the comfort and health issues at the heart of this approach ([Section 5](#)) and the importance of adopting suitable clothing ([Section 6](#)). The energy-use benefit of this strategy is examined in [Section 7](#). An overview of how such a heating strategy relates to current temperature standards is provided in [Section 8](#). The report ends with conclusions and recommendations for future research on the subject ([Section 9](#)).

2. Heating strategies

Traditional houses were heated by open fires and many had fireplaces in most, or all, of the living rooms and bedrooms. During spells of cold weather some or all of these were lit and needed ventilation to keep the fires burning and to prevent carbon monoxide poisoning. The walls of such houses were generally of solid mass, using stone or brick bedded in lime mortar. If not retrofitted with insulation, such walls usually have a poor thermal performance compared to modern construction. Rooms in traditional houses may also have higher ceilings and, therefore, a larger volume to heat. It is estimated that 20% of Scotland's housing stock consists of such buildings, most of them built before 1919.

If a normal central heating system (with boiler and radiators) is installed and run at 20 to 22 degrees Celsius (°C), as is common today, a large amount of energy is required to heat such a traditional house. Because of the rapid rise in electricity, gas and particularly oil prices, the cost of heating older houses is increasingly a concern. Oil is used in many rural Scottish houses as fuel for boilers running wet radiator heating systems.

There are a variety of ways to reduce the heating costs of traditional houses. Obviously, an improved thermal performance of the building envelope (walls, roof etc.) would reduce the heating requirement. There are plenty of options now available to retrofit new building components, such as additional insulation. However, retrofit solutions need to be carefully considered to ensure that they are suitable for use with the existing construction and do not harm the building fabric. (For example, traditional stone walls are, generally, moisture permeable; retrofitting these with impermeable insulation systems can cause fabric deterioration and mould growth.) Some buildings are of architectural or historic interest, and retrofit solutions may be restricted by conservation needs.

Regardless of whether the thermal performance of a building component is improved, another obvious approach to reducing heating costs is by using more efficient heating systems, and also by reducing the general background indoor temperatures and providing comfort where needed with local heaters. This approach also requires a change in the understanding, perceptions, behaviours and expectations of the building occupants about how they achieve comfort in that particular building.

Houses are not heated for their own sake, but to provide their inhabitants with a comfortable indoor environment. How warm people feel depends on several factors beside the temperature of the air. They exchange heat by radiation with the surrounding surfaces in the room. Moving air has a cooling effect, while the humidity of the air has only a small effect in wintertime. Other important factors include the insulation of the occupants' clothing, and their activity. It follows that there is no single air temperature for comfort. A room can feel nice and warm at quite a cool air temperature, if it is not draughty, and if there is a local source of radiant heat or if warm clothing is chosen. It is also worth noting that the heating devices we refer to today as 'radiators' – as used in a wet radiator heating system – transfer heat mostly through convection. The radiant heat given off by such a 'radiator' is normally less than 50%.

Historically, in the UK, heating was largely by open fires, whereas in other Northern European countries more use was made of closed fires in some form of oven or stove, in which the fuel was burnt. Both these types of heaters emit a mixture of radiant and convective heat. If the radiant source is exposed, much of the heating effect for the inhabitants of the room is radiant, either directly from the flames (open fire) or from the hot surface of the appliance (oven or stove). The inhabitants will occupy a space where the operative temperature can change markedly from one place to another. (*Operative temperature* combines the air and radiant temperatures to show their effect on the warmth of the environment.) Such a heating strategy is acceptable – desirable even – in a space where inhabitants have control over their movements and arrangements.

The indoor environments resulting from such a heating strategy may be found unusual nowadays, but they can be refreshing and very comfortable. At first glance, they seem to go against current standards, but a careful reading of the standards shows this not to be so. Current indoor temperature standards have been formulated assuming certain values for activity and clothing insulation, and so the standard calculation method encourages thermal environments that are uniform in space and time, that is to say, not changing from place to place or over time. However, particularly in dwellings, clothing and activity levels are chosen by the occupant in response to his or her circumstances and desires. In short, the standards are concerned with physics and physiology of thermal comfort, to the neglect of social and behavioural insights. The impacts of such standards are discussed in more detail in [Section 8](#). For a fuller description of the physics and physiology of comfort, please refer to [Nicol et al. \(in press\)](#) and [Parsons \(2003\)](#).

3. Background heating and local supplementary warmth

We now explore what might result if, instead of maintaining 20 to 22°C throughout the house and sealing cracks and flues to reduce heat losses by air-infiltration, the interior were to be maintained at a background temperature of, say, 16°C and appropriate local supplementary heat-sources were provided, when and where desired, usually in the form of a radiant heater. In this way occupant comfort is achieved for people seated in the radiant beam of the heater while the larger occupied space remains at the lower temperature. As late as the 1970s, the average house temperature in the UK was 17 to 18°C; yet now, within only one generation, indoor temperatures of 20 to 22°C are expected continuously.

A good overview of keeping warm and comfortable in cold climates was given in L. H. Newburgh's classic book of 1949, *The physiology of heat regulation and the science of clothing* ([Newburgh, 1949](#)). The contributors to this volume gave examples from various traditional cultures around the world. They include examples of traditional winter clothing that provided high thermal insulation, the provision of warmed raised platforms for social intercourse and for sleeping, and the use of heating under low tables. Thermal comfort studies worldwide have since shown that the operative temperatures that populations consider thermally neutral (neither warm nor cool) have varied greatly in different cultures

at different times ([Humphreys, 1975](#); [de Dear & Brager, 1998](#)), mostly, but not entirely, because of differences in their normal clothing.

Even between individuals in one building, the preferred operative temperatures can vary greatly. In their daily life, most people will have a 'normal' thermal experience, which reflects their own personal circumstances and the culture and climate in which they live. In the past, in a large country house in Scotland, for instance, each individual, be it the scullery maid or the owner, had a daily routine that involved clothing, food, activities, furniture, heat sources and bedding that ensured that, during their normal day, they could remain comfortable ([Nicol & Roaf, 2007](#)). Their thermal experience was not uniform in time or in space; rather they would return to a local heat source at intervals during the day.

The lessons from these and other examples from different cultures are simple: If the temperature throughout the dwelling cannot conveniently and economically be kept continuously high (for example, at the levels that have become customary in the UK since the advent of cheap fuel and central heating), it is necessary to wear clothing of higher thermal insulation, or to provide extra local warmth, or both.

One way of providing local warmth is by thermal radiation. Houses in the UK were, until about 1970, normally heated by open fires. The direct heat output into the room from these fires was almost all by thermal radiation. The room air was heated only indirectly. Thermal radiation from the fire fell onto the walls, and other room surfaces, and warmed them; they in turn warmed the room air in contact with them. In addition, some fire places were made of cast iron, which, when heated, would increase the convective heating either in front or behind the hearth. A person seated near the fire received the benefit of its direct beam of thermal radiation. This benefit can be substantial: A beam of radiant intensity of just 50 watts per square metre (W/m^2) produces a temperature rise of about one degree Celsius (or one Kelvin) in an object placed in the beam. The upholstered chair, in which the person sat, sometimes had a high back and 'wings' ([Figure 1](#)), which reduced cooling by draughts. It was also heated by the same radiation from the fire, and so the person did not lose excessive heat to the cooler room surfaces behind.

Tall screens behind chairs were very commonly used to provide a further comfortable 'micro-climate' quite different from the rest of the room ([Figure 2](#)). For the occupant, and to much a lesser extent for the room as a whole, the radiant temperature exceeded the air temperature, a condition often considered desirable for comfort, and one often associated with cosiness and 'thermal delight' ([Heschong, 1979](#)).

Open fires had drawbacks: There was the work of lighting and tending them, and they were thermally inefficient because most of the heat (some 70 to 80%) was lost to the hot combustion gases and entrained air from the room going up the flue. This heat was not totally lost, because the surrounding masonry and chimney stack was warmed by the hot gases in the flue. There were often multiple flues in a stack, often housed within party walls, so there was a degree of secondary warming. Such walls were often plastered directly 'on the hard' to ensure best transmission of the heat from the flue. The combustion of the coal or wood was incomplete, polluting the outdoor air with soot particles and other combustion products. The air going up the chimneys drew outdoor air into the rooms through cracks



Figure 1 Photo of a croft house interior on the Shetland Islands showing a hooded chair to the left of the fireplace. The box would be lined with wool blankets, to keep the chill off the back of the person seated in it, while he or she is nicely 'roasted' from the fire in the front. (Photo © Shetland Museums and Archives)

and openings, and, while this provided more than adequate ventilation, it was also apt to produce unpleasant draughts, especially across the floor. The direction and speed of these draughts would be affected by the location of furniture and their severity by the type of dress worn. Later fireplaces had controllable vents in the floor adjacent to the hearth, to reduce cold air being drawn across the room.

Over the centuries, there have been many improvements to the design of fireplaces, including the cooking range in the kitchen in the later 1700s and the closed-stove room-heater in the living room in the mid 1800s. It is instructive to look at very early hearths to see how and where the radiant heat was directed. A modern closed stove, fired by gas, wood or coal, burns fuel efficiently (perhaps up to 80%). However, the improved efficiency comes at a cost: these stoves tend to produce a high temperature gradient between floor and ceiling, which can cause hot heads and cold feet. The much reduced airflow up the chimney, while reducing draughts, does not, of itself, produce adequate room ventilation. More advanced fires and stoves draw air directly from the outside to avoid draughts, further reducing the room ventilation. Lastly, the output from the stove contains a smaller proportion of radiant heat, and its radiation is diffuse; so the benefit from the direct radiant beam can be much smaller than with a traditional open fire.

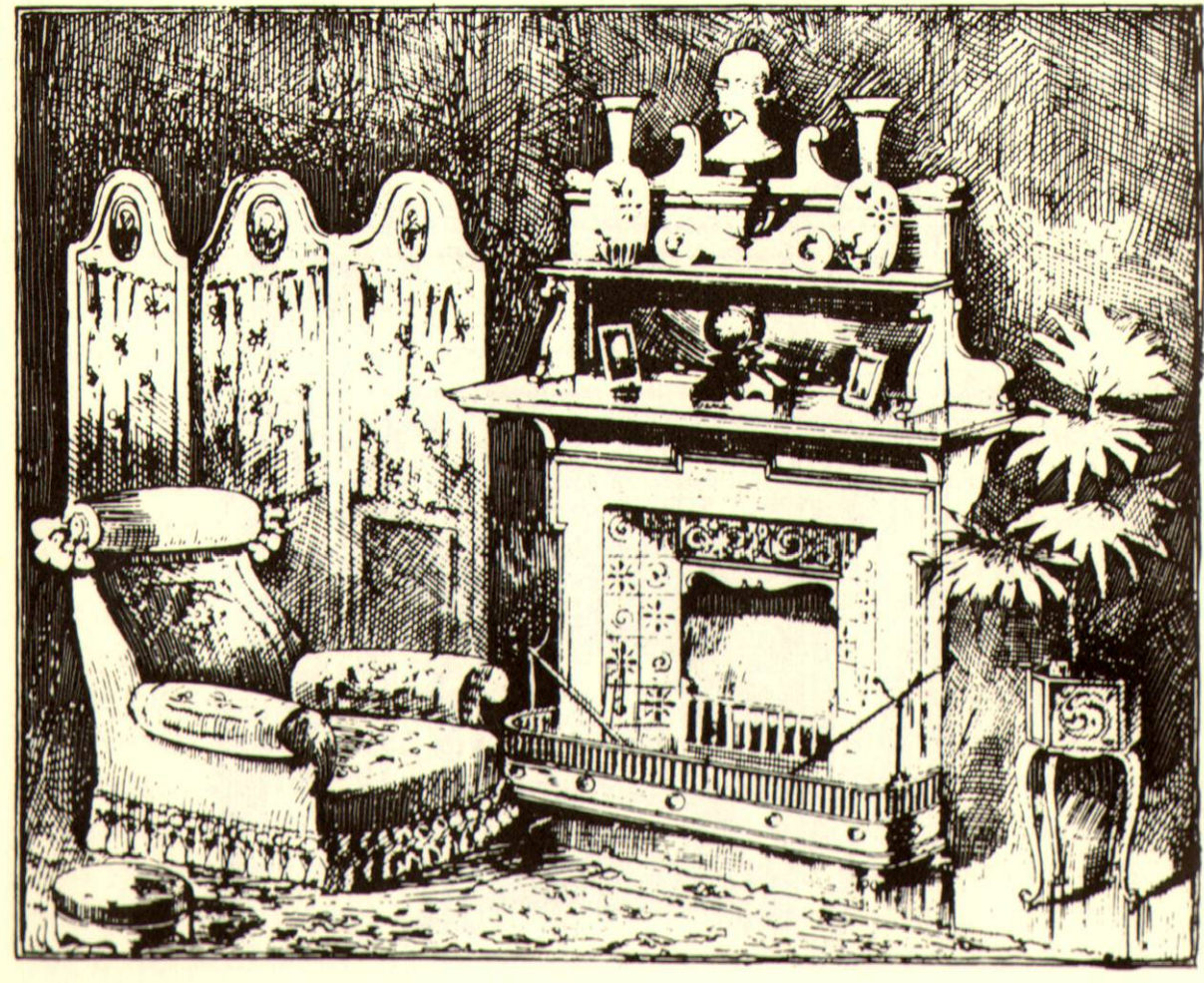


Figure 2 High backed chair and screen by the fire from a trade catalogue of 1895 (reprinted in [Wright, 1964](#), p.146)

4. Supplementary heating appliances

We now consider whether it is possible to obtain the benefits of open fires without their disadvantages. If this can be done, comfort would be possible in older homes with only modest outlay on insulating and sealing the fabric, and without excessive energy consumption.

16°C is a comfortable operative temperature for the activity levels associated with many common active domestic tasks, if people wear ordinary indoor clothing. The statement is necessarily vague, because of interpersonal variation, because of the different degrees of exertion needed for such tasks and because of differences in clothing. However, most people would be comfortable, or, if they were not, they would find it easy to secure comfort by making small and ordinary variations in clothing.

For sedentary activities (reading, watching television, studying) it is different. For people wearing normal indoor winter clothing, an operative temperature of some 21 to 23°C is

normally about right. A good thick extra jumper would lower this by about two degrees. Suppose that 21°C were required, five degrees higher than the 16°C suitable for more active people. This would require a beam of radiant intensity from the appliance of some 250 W/m², if the background operative temperature were 16°C. This intensity is about one quarter of that received by a person in full sun. If the person were seated in an upholstered winged armchair, the requirement would reduce to perhaps 200 W/m², because of the warming of the chair and the consequent slower rate of heat loss from the body.

During the oil crisis of the 1970s, radiant stoves that had suitable characteristics were developed at the Building Research Establishment (BRE) (Humphreys, 1980). We are not advocating that these particular devices should be used; rather we use them to show that it is practicable to develop local heat sources that produce a comfortable radiant environment.

The stoves were designed to produce a horizontal beam of radiant heat confined to the lowest metre of the room, where people sit, so increasing the intensity within this occupied zone (Figure 3). They had the additional advantage of little variation of intensity in the vertical dimension within the depth of the beam. Because the beam of heat is in the lower portion of the room only, the room feels cool and fresh to a standing person, while feeling warm for someone sitting down. The beam spreads in the horizontal plane only, so the loss of intensity with distance is much less than from an open fire.

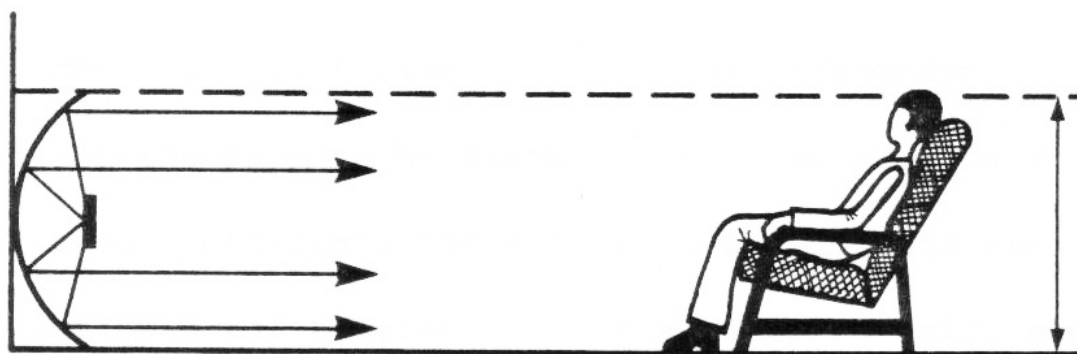


Figure 3 Schematic diagram showing the principle of the radiant stoves (published in Humphreys [1980])

A technical note may help explain this feature. Thermal radiation spreading out from a small source of heat has an intensity that reduces according to the inverse-square law. That is to say, doubling the distance from the source would divide by four the intensity of the radiation received. That is not so with these appliances, because the reflector prevents the vertical spread of the radiation, while still permitting the horizontal spread. This means that the intensity of the thermal radiation reduces in simple proportion to the distance from the source: doubling the distance halves the intensity rather than dividing it by four. Thus the appliance provides more heat at a greater distance than would a normal fire of equal radiant power.

The appliances were not produced commercially, because fuel again became cheap and plentiful, but two prototypes are still in use and well liked after more than 30 years of continual use (Figure 4). A further prototype of modified design, called the *Heatbox Radiant Stove*, was built and has been in use in a church community-room for several years and is much liked (Figure 5). So the prospect is good that suitable radiant appliances could be developed.

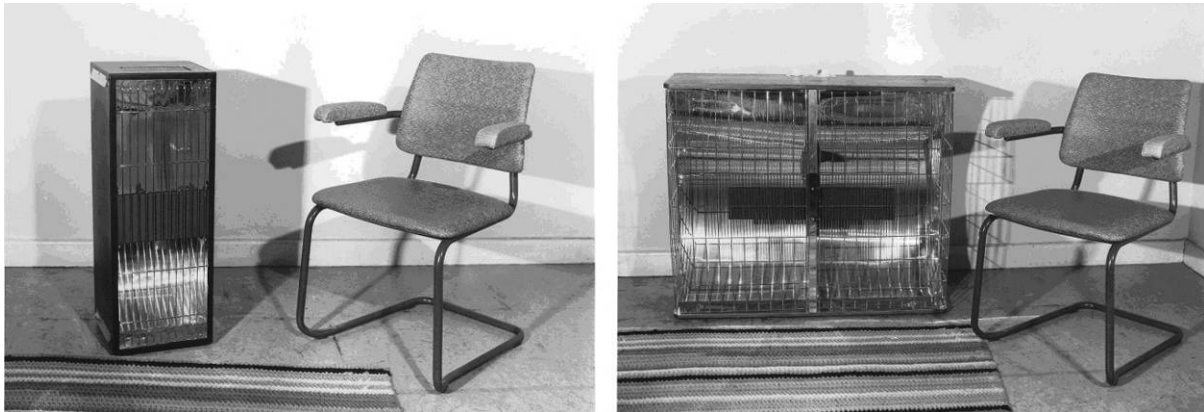


Figure 4 Prototype radiant stoves from the last energy shock period in 1973. Left photo: compact version with approx. 1 kilowatt (kW); right photo: dual control version with approx. 2 kW.



Figure 5 The prototype Heatbox Radiant Stove (dual control with 2×1 kW) installed in the community room of a church (Photo © M. Humphreys)

The appliances are most simply constructed to use electricity, but a gas-fired prototype was also designed and built. The present objection, on environmental grounds, to the use of electricity for heating will become less strong in the future, for it is the intention of the Scottish Government to increasingly derive Scotland's electricity from carbon-neutral sources. However, at present, the cost of electricity to the householder is some three times that of gas, and this would place an unacceptable burden on the occupants; so gas-fired stoves with the appropriate radiant fields would need to be developed.

The radiant asymmetry produced by these appliances can be greater than that recommended by current standards for thermal comfort. However, the standards were established in climate chambers under qualitatively different radiant environments and do

not seem to apply to these heaters that provide horizontal beams confined to the lower part of the room. (We will explore background heating in relation to current standards in [Section 8.](#))

The open fire used to be the focus of the living room; so perhaps radiant stoves should be placed in the same location. Or maybe the television set is now the focus of the living room; so perhaps the radiant appliance might serve as a table for it. Careful design is needed in historic houses so that the new appliance is fitted sensibly into its surroundings (Figure 6).

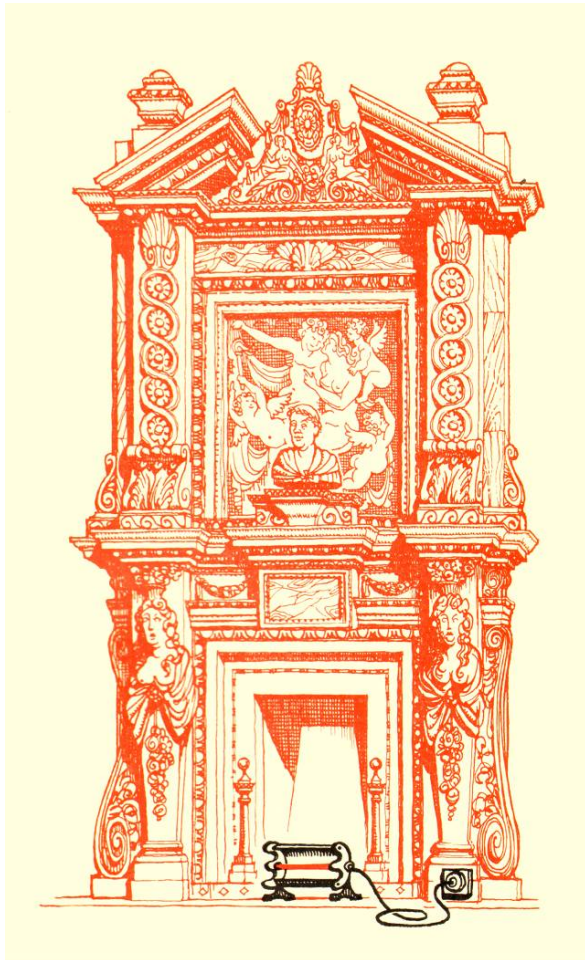


Figure 6 A humorous take of retrofitting a historic fireplace with a radiant heater (Wright, 1964, image on dust cover)

The energy saving from fires of this type arises from their better distribution of radiant heat, when compared with more conventional designs that act more as point sources of radiation. More details of this type of radiant stove are given in the paper *A radiant domestic fire designed for economy and comfort* which concludes: “The saving from these devices is difficult to estimate because it depends on the design and construction of the room. Further difficulties arise because the radiant environment is not uniform and because there is no ‘standard fire’ against which the comparison should be made. Nevertheless it is clear [from laboratory measurement] that over a substantial area of the room the new fire is some 1.5 to 3 degrees better than more normal radiant fires of 1 kW output. It may be supposed then that a 2 kW model would be about 5 degrees better than conventional models.” (Humphreys, 1980) (We will consider the energy use of background heating and supplementary warmth further in [Section 7.](#))

For sedentary work at a desk, local heat can be provided under the work surface, and the advantages of such a system have recently been explored by a research team at the Centre for the Built Environment, University of California, Berkeley (Zhang et al., 2009). They find that such systems provide comfort and sustain good task performance with very small power consumption (Figure 7). For dining at a table, the logical place for the heater is under the table, as was the custom in the Middle and Far East, and in some places still is.



Figure 7 Radiant foot warmers, now being experimented with in the USA, could avoid the need to heat the room for certain periods of the year. (Photo © E. Arens)

Bedrooms at the background temperature of 16°C are quite satisfactory for sleeping, with duvets of sufficient thermal insulation (about 12 tog), and for dressing and undressing, but at these bedroom temperatures people often like the bed to be pre-warmed with a hot water bottle or an electric under-blanket. Supplementary heating might be desired for some more extended activities and could be simply provided by a radiant appliance. If the bedroom doubles as a living room or study, suitable local heat will be needed for those times, too.

Bathrooms would perhaps need supplementary heating for those times when people were bathing or showering. Radiant appliances are preferable, because they provide warmth without much increasing the rate of evaporation of moisture from the wet skin. Blown-air heaters can be unsuitable in bathrooms, because the increased evaporation, caused by the moving airstream, can cool the skin, rather than warm it.

Open fires were controlled by the room's occupants according to their needs and desires, subject to financial constraints. There is little experience of controlling systems with supplementary radiant warmth in dwellings. So control of a supplementary radiant system will be a matter for learning from experience. Some suggestions can be made:

- The background heating, provided by a conventional radiator system or in some other way, could be controlled to a room temperature of 16°C (or whatever value is decided upon after more experience). This could be done with thermostats that respond to air temperature alone or that are shielded from direct radiation. It would be wise to have the rate of heat input to the system additionally limited in relation to the outdoor

temperature. This is to prevent excessive opening of windows during wintertime as a means of temperature control (a procedure that can consume vast amounts of energy, when thermostatic radiator valves alone are used).

- The radiant appliances could be controlled manually. They would need to have a range of settings of the power-level. It would also be good practice to have them switch off automatically when a space becomes unoccupied for more than a few minutes, provided that mechanisms are such that the heater did not switch off just because the room occupant was sitting still or having a nap.

5. Background heating and health concerns

With a cooler background indoor air temperature, less energy is lost through ventilation (because the temperature difference between inside and outside is smaller) and for the same reason less energy is required to heat the replaced air to the background temperature. Ventilation is required to reduce the risk of condensation and the associated mould spores that can result from it. Cooler indoor temperatures also reduce the prevalence of house dust mites. The improvement in indoor air quality consequent upon increased ventilation rates (provided the outdoor air is clean) would be likely to reduce respiratory illness, such as asthma and bronchitis, and perhaps reduce the incidence of airborne infections. The increased ventilation would also reduce the concentration of volatile organic compounds off-gassed from building materials, furnishings and household cleaning products; some of these compounds are injurious to health.

In winter, the increased ventilation would lower the indoor absolute humidity. Whether this would be advantageous depends on the moisture input to the dwelling from occupancy (breathing, cooking, washing floors, drying clothes, showering etc.). The indoor air could become undesirably dry during exceptionally cold periods when the water vapour pressure in the outdoor air becomes very low. However, problems arising from high humidity in dwellings are more common than those from low humidity; so, on balance, increased ventilation would be beneficial.

A minimum bedroom temperature of 16°C for young babies is recommended to reduce the risk of hypothermia, but we have been unable to find a basis for this recommendation. So, for example, the National Health Service (NHS) recommends parents “to keep your baby’s room temperature between 16 to 20°C. Ideally the room temperature should be 18°C.” (NHS, 2010). So it may be that babies’ bedrooms should be maintained at above 16°C for the first few months of life. An alternative would be to use low-power local supplementary heat. Nursing mothers in the baby’s bedroom would need to have supplementary heating available, too.

Coldness increases the risk of stroke in the elderly. The effect arises from coldness of the limbs and the consequent vasoconstriction increasing the likelihood of a blood-clot. It is unlikely that the proposed conditions would increase the incidence of stroke, as people active at 16°C would not be cold and sedentary people would have supplementary radiant heat sufficient to keep their limbs and extremities warm.

Old people suffering falls in cold rooms have an increased risk of death, if left unattended for a long period. Survival times depend upon (among other things) the room temperature and the clothing that is worn. This risk would need to be quantified to make sure that a safe temperature is provided. We are unable to find quantitative information about this risk.

Special provision might perhaps also be needed for people with some particular physical ailments or disabilities.

High temperature surfaces have the property of breaking down into smaller particles any dust that settles on them, and they oxidise it, so emitting combustion products. This gives the characteristic smell of 'hot dust' when heating elements are switched on, or stoves are newly lit. Excessive exposure to this particulate matter can cause irritation to the mucous membranes, and long exposure can harm the lungs. The design of heating appliances should be such as to minimise the amount of dust that settles on the element, and exposed heating elements should not be used in dust-laden atmospheres.

Radiant stoves can be designed to be inherently safe. The BRE stoves described earlier in this report were so designed: it was impossible to burn by approaching too close to the appliance, at no place was the intensity of radiation high enough to cause pain or to scorch clothing, and the body of the appliance remained cool. An adequate safety-guard around the element was provided. All appliances used to provide local heating should be designed to be similarly safe in use.

6. Importance of suitable clothing

There is an advantage to be had from flexibility in habits of clothing. People can adopt the custom of wearing warmer clothes for sedentary activities. Indoor coats, similar to dressing-gowns or housecoats, were commonly worn for activities such as reading or sewing, and were put on as a matter of course. Traditionally, many houses were occupied by people who spent much more of their time outdoors as well as in unheated parts of the house, and they would habitually wear more clothes both indoors and outside. The custom of wearing almost summer-weight clothing indoors all year round and for most activities is recent and can, presumably, be reversed.

Clothing is not without cost. However, at home, where the density of occupation is low, it is usually cheaper to have a cooler room temperature and to wear warmer clothing. The chosen balance between clothing and room temperature is a social construct and, in part, a matter of custom (Shove, 2003). A hundred years ago it was common, even in wealthy homes with no restriction on the cost of winter heating, for the rooms to be cool and for warmer clothing to be worn. It is likely that in the future increased energy costs will nudge clothing customs in that direction.

7. Energy use of background heat and supplementary heat

Provisional estimates can be made of the percentage savings that might be expected from heating to a room temperature five degree lower than usual and supplementing it with local warmth. For our estimate, we have used annual (heating) degree-day data for Edinburgh, taken from CIBSE's *Guide A: Environmental design* ([Chartered Institution of Building Services Engineers, 2006](#)). (The degree-day index is the accumulated temperature difference between the prevailing external temperature and a selected 'base temperature'. Heating degree-days, expressed in Kelvin multiplied with days [K-days], indicate the severity of the heating season and, therefore, heating energy requirement.) We have compared base temperatures of 13°C with 18°C and also 15°C with 20°C. These comparisons show reductions in heating degree-days of 47 and 42% respectively (see [Table 1](#)). These indicate the likely reductions in annual energy use for heating the dwelling to a lower background temperature.

Table 1 Estimated savings for Edinburgh for a difference in background heating temperature of five kelvin. Heating degree-day data from CIBSE's *Guide A: Environmental design* (CIBSE, 2006), p. 2-13, table 2.21. (Values obtained by interpolation where necessary.)

Base temp (°C)	Degree-days	with 20% allowance for local supplementary heat	Base temp (°C)	Degree-days	with 20% allowance for local supplementary heat
13	1789	2108	15	2386	2728
18	3385		20	4098	

Reduced to (%)	53	62	Reduced to (%)	58	67
Saving (%)	47	38	Saving (%)	42	33

In cold weather it is unnecessary to add an estimate for the energy used by the supplementary local radiation, because any use of these appliances would reduce correspondingly the energy used by the background heating. In spring and autumn, if the indoor temperature would have been at or above the chosen level of the background heating, the energy demand of the supplementary heating appliances would need to be estimated. If we assume that providing supplementary local warmth would use as much as a fifth of the estimated energy difference (perhaps an over-estimate), we find savings of 38% and 33% respectively. We surmise that energy savings of some 30% to 40% would be achieved.

The approximate nature of this estimate is evident and it would be good to make independent estimates by thermal simulation of a variety dwellings and occupancy patterns. The savings are not specific to any particular construction, but arise from the change in heating strategy alone.

8. Supplementary heat and current standards

International standards for indoor environments have, until recently, been based on scientific experiments undertaken in climate chambers (special laboratories where the environment can be controlled by the researchers). The experiments have enabled scientists to formulate a relationship between the sensation of warmth of the subjects in the climate chamber and the temperature, humidity and air-movement they were experiencing. Also important, of course, were the thermal properties of their clothing and the activity they were engaged in at the time.

The climate chamber experiments, upon which the standards rest, were conducted during sessions of up to three hours, during which the conditions were kept constant. The subjective assessment at the end of the period was taken to be definitive. As a result, the constancy of conditions was embodied in the relationships obtained. This assumption of a constant environment meant that the results are most readily applicable to such an environment. Buildings where the indoor environment is maintained at a constant level are found to be relatively well described by the relationships established from the climate chamber experiments.

This method of development, therefore, tends to restrict the applicability of the standard to buildings which are air-conditioned or where the indoor environment is kept nearly constant over time by a heating system, such as central heating. The standards also assume that the temperature should be kept relatively constant throughout the building or the room.

Standards are developed by international, supranational or national bodies, such as the International Standards Organisation (ISO), the European Committee for Standardisation (Comité Européen de Normalisation, CEN), the British Standards Institution (BSI) and the American National Standards Institution (ANSI). The idea is to set guidelines for the regulation of the quality of a product or a process, such as a standard methodology to measure an environment. These bodies are often formed of those who have an academic or institutional interest in the product or process. (A particular example is that of the United States, where the American Society of Heating, Refrigerating and Air-Conditioning Engineers [ASHRAE] has actually set the US standard for indoor environments, *ANSI/ASHRAE 55-2010, Thermal environment conditions for human occupancy* [ANSI & ASHRAE, 2010]).

As a result, the underlying assumptions embodied in standards can tell us about the approach which is currently taken by the academics and professionals. In the case of indoor environmental standards, they tell us that the aim of the professional is to provide comfortable environments which vary little in time or space. Such an approach is driven by the need of the heating, ventilating and air-conditioning industry in particular, and the building industry more generally, to specify 'comfort' in a way which is provided by the products they are selling (Fanger, 1970, p.3).

Recently, it has been realised that the models are inadequate in many buildings, particularly at times of year when heating is not necessary and indoor conditions are typically variable.

It has been found that indoor environments considered comfortable by inhabitants are far less closely defined than the standards would predict. This is partly due to the efforts building occupants make to adapt their indoor environment, or themselves, to achieve comfort.

The alternative approach, that comfort is a goal which occupants should be enabled to seek (Shove, 2003), was not acknowledged in these standards. In consequence of more recent research, some standards now incorporate an 'adaptive' element for naturally ventilated buildings, for example, the US standard *ANSI/ASHRAE 55-2010*, and the European standard *EN 15251, 2007*, (implemented in the UK as British standard *BS EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics* (BSI, 2007)).

Whilst the adaptive elements in the newer standards acknowledge some of the variability of indoor environments in time, they still assume that we should favour no variation from place to place. The opportunity of moving around within a space to achieve comfort is not acknowledged. Yet, for instance the British standard *BS EN 15251:2007* claims applicability of the recommendations of the standard to "single family houses, apartment buildings, offices, educational buildings, hospitals, hotels and restaurants, sports facilities, wholesale and retail trade service buildings" (BSI, 2007, p.6). The standard does admit that the bulk of the scientific evidence it is based upon is from offices. It reflects 'best thinking' on the subject matter it covers. Buildings which do not follow the advice written in the standard could be seen as contrary to normal practice and open to question. So applying a heating principle which was used traditionally in many older houses can appear strange to today's architect and engineer. The current standards simply do not visualise the ways of securing comfort that are common in occupied dwellings without central heating.

However, nothing in what we are suggesting is in contravention of the standards, if they are carefully examined (except perhaps the matter of radiant asymmetry discussed above). The temperature of 16°C, according to the standards, is a perfectly possible temperature for comfort, if the clothing and activity are appropriate.

Standards are, generally, seen as guidance rather than law. But an insistence on uniform conditions would make it impossible for our proposed strategy for comfort, as outlined in the sections above, to be adopted. It would be desirable to have a standard more obviously applicable to buildings which are heated in the way suggested in this report; for we do not want to accept the situation in which these buildings are seen as inferior by definition. One of the reasons why scientists were moved to ensure that standards incorporated an allowance for buildings whose environment changed with time (the 'adaptive' standards) was that such buildings were in some ways superior to air-conditioned buildings. The occupants liked them, and they were intrinsically low-energy buildings. We have shown that this can also be true of buildings which use 'traditional' heating principles, thereby giving a choice of environments within one space.

We suggest a minimum indoor temperature of 16°C to ensure the health of inhabitants with an assurance that they have ability to provide local increases in operative temperature of

appropriate intensity and availability for the tasks envisaged for the space. This temperature 'boost' can be provided by radiant heating, where this is compatible with comfort, or by local convective heating, for instance under a desk or table. The exact way, in which the temperature boost will be delivered, and the operative temperature it should provide, will need to be the subject of further research. Also necessary will be research into the most appropriate technology.

Research into the kind of temperature regime we are suggesting will necessarily focus on domestic properties where there is the greatest need for this kind of approach, but the resulting findings could well give insights for other environments where inhabitants have diverse requirements (for instance retail outlets, where the needs of staff and customers may conflict). At the same time surveys of current practice in such environments may in turn help us to improve the provision of comfort in older houses.

9. Conclusions and research recommendations

In this report, we have shown that heating houses to a modest background temperature and providing local supplementary warmth could create good thermal comfort and make energy savings compared with heating the whole interior to a temperature normally expected today. Although this cannot reduce the energy consumption to the levels expected of newly built houses with modern standards of insulation, it can be used together with other technical upgrade measures. It seems that, on balance, the suggested environments would be better for the health of the occupants than those often used today, but special provision might be needed for the aged, for the newborn and perhaps for people with some particular physical ailments or disabilities.

To continue the exploration of the matter, the following research would be desirable:

- The estimates of energy saving should be further explored by the thermal simulation of a selection of traditional houses, and using a variety of occupancy patterns.
- There is a need for suitable radiant appliances to be identified and for their designs to be developed. They should be tested not only in the laboratory, but also in daily life, to evaluate their ability to provide a comfortable environment in everyday circumstances.
- The method of control of background heating with supplementary local warmth is a topic requiring development. The aim of any control system should be to enable comfortable conditions to be secured with minimal energy use.
- The thermal environment would be different from that to which people have become accustomed in this generation. This difference would necessitate developing and providing appropriate guidance to residents.

We have also shown in this report that houses – and traditional houses in particular – are ill-served by the existing standards for thermal comfort. There is, therefore, a need for a new standard, or guideline, specifically for the indoor environment in houses (and other buildings with variable indoor environments). Such a standard would necessarily be

adaptive in nature. At a minimum, it should cover the thermal environment and air quality. The process by which a new standard can be created is long and cumbersome, and needs to rest on incontrovertible evidence, especially when, as here, commercial interests are involved, for example those of the heating, ventilating and air-conditioning industry. Whilst the underlying physiology on which such a standard might be based is fairly incontrovertible, the approach where comfort is seen as more than the provision of a constant and uniform indoor environment needs to be tested and surveyed in the field. It is proposed that further research should be undertaken in this area.

We have shown in this report that background heating with local supplementary warmth is a heating strategy suitable for houses – and suitable for traditional houses in particular – which can help to create healthy indoor environments with good thermal comfort whilst saving energy and costs. We believe that such a heating strategy should more often be considered, instead of relying only on technical upgrades of building fabric and services; indeed, it can easily complement technical upgrades and achieve even better savings.

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