HEATING OF BUILDINGS BY MICROWAVES

Derek J Croome Hanna Swaid
Department of Construction Management & Engineering
University of Reading
Reading RG6 2BU, UK

Introduction

The incentives for introducing microwave technology for heating of buildings relate to a series of common objectives sought in the environmental design of the built environment:

(*i*) **to effect energy savings:** with the gradual depletion of conventional energy resources and the adverse implications of burning fossil fuels on the environment, energy conservation schemes are becoming increasingly essential.

(*ii*) **to improve indoor air quality and comfort conditions:** recently, an increasing number of buildings fail to provide healthy and comfortable conditions to the occupants, thus affecting their well-being and productivity. Unfortunately, some energy conservation measures, e.g. limitation of fresh air supply and number of air changes, inadvertently result in deterioration of the indoor environmental conditions.

(*iii*) **to implement high-technologies in the building industry:** implementation of high-technology products in tempering and control of the indoor environment contributes towards further modernization of the building industry and attaining energy savings as well as improvement of the living and working conditions in buildings (1).

Heating of buildings results in high energy consumption and wastage even greater if one includes all the inefficiencies in energy generation, transmission, and distribution. However, buildings are not always designed to minimise consumption of energy. The reason is that the return on capital is normally marginal and hence it is more "economical" to waste energy in heating than to tie up a large amount of capital in some outdated energy saving scheme.

Most energy saving schemes in low energy buildings rely mainly on thermal insulation and draught-proofing. The thermal inertia of a building is much more difficult to handle. It is still impossible to heat a room without also heating a substantial fraction of its structure, heat that cannot be recovered once the room is unoccupied (although it helps to alleviate condensation in some cases).

Moreover, there is the question of heat losses through ventilation. Do we really need N changes of air per hour, or would it be equally effective and healthy to replace only the CO_2 with clean Oxygen? (dust and other undesirable products, would be removed by using suitable filters).

Consequently, for many non-continuously occupied buildings an "ideal" heating system must provide a high degree of cheap thermal insulation, fast response, and low thermal capacity thus enabling an effective control of the system from "off" to "on".

This paper presents a radically new method for heating buildings by using microwaves. It fulfils, almost completely, all of the basic requirements for an "ideal" system and has additional intrinsic features that no other system can match.

Microwaves

Microwaves occupy the region of electromagnetic spectrum between radio waves and infrared (2); in terms of frequency this range is 1-100 GHz (GHz= Giga Hertz= 10^9 cycles sec^{-1}).

Industrial applications of microwaves are quite common, mainly for heating or drying, with power levels up to 100 kW. To avoid interference between various users, the microwave spectrum has been subdivided into a number of bands, the industrial bands being around 0.915 and 2.45 GHz, the latter more commonly used.

The main advantage of using microwaves is that they can penetrate deeply into the material and heat almost the whole volume simultaneously, in contrast to infrared which heats only the surface, the interior being heated gradually by conduction and consequently being a much slower heating process. This is the reason why microwave ovens cook faster than conventional methods.

For industrial applications, the magnetron is the most efficient microwave generator with around 70% efficiency; the remainder of the energy being dissipated in the magnetron shell which is water or air cooled. There is a slight inconvenience, namely, that magnetrons operate at relatively high voltages, between 4-6 kV, but fortunately the necessary power supply is relatively cheap and very safe. The typical life of an industrial magnetron is about 2000 hrs. Since the present application is only intended for low energy buildings, the magnetron will operate intermittently.

Microwave Heating of Panels

Heating a building or a room by direct irradiation with microwaves is not practical for the following reasons:

(*i*) even under uniform illumination, various parts of a human body would not absorb microwaves at the same rate, resulting in uneven heating and probably discomfort;

(*ii*) similarly, (i) is equally applicable to all objects in a room, with additional possibility that metallic objects could cause sparking and hence represent a fire hazard;

(*iii*) there is some evidence that all high frequency radiation, unless very weak, represent a biological hazard and, therefore, is unacceptable above certain safety limits (of intensity and time of exposure).

Clearly then, the microwave heating method has to be indirect. This can be achieved quite easily by lining selected walls with large panels which are internally heated by microwaves.

Microwaves from one or more magnetrons are injected into the panel cavity at convenient points with minimum power reflections. A metal skin prevents the interaction of microwave fields with the supporting wall. Microwaves travel through lossless thermal insulation into the absorber sheet which forms the other side of the microwave cavity. With a suitable choice of relevant parameters to achieve necessary matching, all microwave energy would be dissipated in the absorber layer, thereby increasing its temperature. Microwave leakage into the room from a microwave absorber layer is prevented by ensuring that the fields in the absorber are evanescent, decaying rapidly towards the outer surface. As an additional precaution, a conductive finish is applied to the surface of the microwave absorber. Thermal insulation, if sufficiently lossless, may fill the whole cavity without any adverse reaction.

For optimum utilization of energy and comfort, the panel temperature would be highest at floor level, progressively falling off towards the ceiling. The overall input power level can also be varied by changing the duty cycle, i.e. the time intervals a magnetron is "on" and "off". Furthermore, hot air from the magnetron cooling circuit can be ducted into the room, thus improving overall efficiency even more.

Clearly, the thermal inertia of a panel is very low because only the thin layer of the microwave absorber is heated. Since panel surfaces are directly heated, air circulations due to thermal gradients are reduced. Energy is also saved by suitably adjusting the vertical heating profile of panels.

The response of this system is almost instantaneous, and it can be electronically controlled and also set to respond to external ambient conditions, thus utilizing energy more efficiently.

Microwave Absorption and Heating Response

The limited knowledge about dielectric properties of of common building materials reveals that they have low absorptivity to microwaves in the 0.915 and 2.45 GHz frequency bands. The amount of energy a material absorbs at radio and microwave frequencies is known as the **loss factor** (ε_r''). The power absorbed by a given material heated by microwaves can be calculated (3, 4) by the equation:

$$P=2\pi fE^2\varepsilon_0\varepsilon_r'' \qquad (1)$$

where P is the volumetric power density (Wm^{-3}), f is the applied frequency (Hz), E is the electric field across the material (Vm^{-1}), ε_0 is the dielectric permittivity of the space (8.85×10^{-12} Fm^{-1}), and ε_r'' is the loss factor of the material.

It is clear from eqn.(1) that the rate of energy absorption in the heated substance is linearly proportional to its loss factor and the frequency of the radiation. It must be pointed out that the loss factor is itself frequency and temperature dependent. Water is particularly receptive to dielectric heating and has very high loss factors of 18 and 100 for frequencies of 3000 MHz and 10 MHz respectively. Little is known about loss factors of building materials (5). For comparison, dry sandy soil has poor loss factors of 0.016 and 0.04 respectively (3). However, it is possible to modify a low loss factor material without altering its other properties, by using suitable additives which must themselves have high loss factors. The development of such efficient microwave absorbers is essential for the efficiency of microwave heating of buildings.

The heating (temperature) response of a material per unit time ΔT is given by eqn.(2)

$$\Delta T=P/\rho c_p \qquad (2)$$

where P is the absorbed power density from eqn.(1), ρ is the density of the material (kgm^{-3}), and c_p is the specific heat of the material ($Wh\ kg^{-1}K^{-1}$)

Clearly, ΔT is proportional to the input microwave power and inversely proportional to the density and specific heat of the absorbing material. Since P in eqn.(1) is proportional to the electric conductivity σ of the microwave absorber, eqn.(2) can be restated as

$$\Delta T=\frac{C\sigma}{\rho c_p} \qquad (3)$$

where C is a constant.

Eqn.(3) may be regarded as the heating response of a microwave panel; it also implies that the microwave absorber should be as thin as possible. However, for satisfactory matching and acceptable attenuation across it, there is a minimum thickness which has to be determined by the field analysis of the complete panel cavity.

Conclusions

Unlike any other existing system, the described microwave heating method meets most of the requirements of an "ideal" system. It can provide the highest possible degree of comfort by suitably setting the heating profile of each panel; offers fast response and is very flexible; is capable of automatic electronic control, taking into account the external ambient temperatures. It uses low thermal inertia panels, which, being integrated with necessary thermal insulation, can result in negligible energy losses from the building. The design of a panel is such that it can be installed without any costly structural modifications.

However, there are also some disadvantages such as the relatively high capital cost of suitable magnetrons. Industrial magnetrons of 3kW or more are comparatively much more expensive, being manufactured in considerably smaller numbers, and hence the price could significantly drop if the demand were substantially increased. Some further reduction in price could be effected by widening frequency tolerances, so that the yield is improved, or even better, by designing a new magnetron specifically for the heating of buildings. In addition, it could be argued that the increased capital cost of the magnetron is offset by low maintenance costs and a substantial saving in plantroom space.

Acknowledgements

The authors wish to express their gratitude to Dr. R. Yell of the National Physical Laboratory and Dr. M. Alcock of the Atomic Energy Authority for their constructive comments on a related research proposal submitted to the Department of Trade and Industry (UK). The contributions of the cooperating companies in the project: Western Dynamics Ltd. (Dr. B. Minakovic), ERA Technology Ltd. (Dr. D. Adamson), and Microwave Heating Ltd. (Mr. R. Shute) are also appreciated.

References

1. D.J. Croome, "Building services engineering - The invisible architecture", Building Serv. Eng. Res. Technol., 11, 27 (1990).
2. A.C. Metaxas and R.J. Meredith, "*Industrial Microwave Heating* ", Peter Peregrinus Ltd., London (1983).
3. The British National Committee for Electroheat, "*Dielectric Heating for Industrial Processes* ", BNCE, London (1983).
4. A.R. Von Hippel (ed.), "*Dielectric Materials and Applications* ", MIT Press, Cambridge (1966).
5. E.C. Okress (ed.), "*Microwave Power Engineering: Vol.2* ", Academic Press, New York (1968).