Reports

Radiant Heat for Energy Conservation

Abstract. *It is proposed that human comfort could be provided in otherwise chilly surroundings by filling the occupied space with electromagnetic energy of centimeter wavelength. Very considerable reductions in the consumption of energy required for the heating of buildings should result from the lowering of interior temperatures thereby permitted.*

Hazards to health that might be associated with the increasing employment, for many purposes, of electromagnetic radiation often imprecisely categorized as "microwaves" have recently received considerable public attention. A most emphatic indictment was the main message of a widely noted recent book (*1*). One reaction to the developing concern is a Notice of Inquiry from the Federal Communications Commission, general docket 79-144, requesting opinions and advice related to the responsibilities of the FCC as licensor of the generating equipment involved.

The purpose of this report is to call attention to the possible great social benefit that could be derived from the use of microwave radiant energy to provide directly the warmth needed by human beings and other living creatures. A strong motivation for the proposal at this time, in spite of growing concern about possible dangers, is the view that such use could contribute importantly toward alleviating the developing world energy crisis. By delivering heat energy directly to the occupants of an enclosed space, rather than to the enclosure or to the space itself, body warmth and personal comfort could be maintained at far lower environmental temperatures than those that have become conventional, especially in the United States, in the departed era of cheap energy. The energy losses through roofs, walls, and foundations, which are roughly proportional to the differences between inside and outside temperatures, would be reduced accordingly. In some climates space heating might be entirely eliminated and, in others, heating of buildings might be reduced to a level sufficient only to avoid freezing and discomfort from contact with cold objects. Some inanimate objects might also be heated by use of materials chosen to absorb microwave energy.

The main mechanism whereby tissue interacts with microwave fields of centimeter wavelength is the dielectric relaxation of the polar molecular water component. This develops heat essentially through friction as the molecules attempt to follow the oscillating electric field but are impeded by viscous drag. The absorption is so strong that fields of this wavelength are attenuated in millimeters of depth, so the warming is a surface effect essentially in the skin and should seem little different from the warmth conveyed by the radiant heat from a warm stove. In the latter case, the main wavelengths involved are less than 1 mm, but weak centimeter waves are also so included. Microwaves can be more efficiently reflected from walls than can infrared rays, if the walls are given the properties of a good metallic conductor. Neither the walls nor the air need be significantly heated in the process. In this way the room would become a resonator supporting a large number of modes of high numerical index that tend to overlap in frequency. Thereby, the room would be filled relatively uniformly with radiant energy. Metal foil walls could readily be decorated with coverings that would have little effect on their reflectivity. Large apertures, such as windows and doors, might be covered with metal screening to avoid energy losses. An occupant would then experience uniform warming irrespective of his location in the room. Of course, the microwave feed should be so designed that objects or occupants do not intercept the radiation directly. Occupants would dampen the modes of the box heavily, so a system of controls would be required to maintain the energy density at levels appropriate for a varying number of such occupants (and other absorbers). These controls could hold fixed the energy density sensed at some suitable set of locations. A simpler but less uniform and efficient scheme would be the direct illumination of the occupants without the use of reflecting surfaces as room boundaries. In that case much larger total energy would be lost in heating the space and the heat delivered to the occupants would be dependent on their positions. Microwaves should penetrate through dry clothing of many kinds more effectively than do infrared heat waves. Because of this there could be a useful net containment of the warmth in a manner similar to that achieved with visible radiation in greenhouses.

As an index of the energy levels needed to maintain comfort, one might note that the heat generated in the human body by metabolic processes is at the rate of about 60 W. Human thermal comfort is believed to require maintenance of the skin temperature at about 34°C, which most persons achieve in a sedentary state in surroundings at about 22°C with normal indoor clothing. The 60 W generated in the metabolic processes evidently support about a 12°C temperature rise of the skin above the surroundings in dissipating the metabolic heat, through all the mechanisms of bodily heat loss. If 60 additional watts of energy were externally supplied to the surface of the body, it seems reasonable to suppose that the desired skin temperature could be maintained in surroundings 24°C below skin temperature, or 10°C. In this way a 10°C room temperature should be rendered as comfortable as one at 22°C without radiation.

The current radiation protection guide in Western countries allows incident field strengths of 10 mW/cm^2, without reference to wavelength. The power incident on a human being in a radiation field of that intensity might be of the order of 100 W, estimating the effective area to be about 1 m^2. The fraction of this incident flux absorbed by the skin is reported to be about 0.35 at the frequency of 2.45 GHz used by microwave ovens, but there is evidence that it rises to 0.8 at 8 GHz and to 0.95 in the range 40 to 90 GHz (*2*). It thus appears that this proposal is compatible with the current radiation protection guide, even though the guide was set under the assumption that radiation could only be deleterious. Experiments are needed to establish suitable parameters in practice.

It is often desirable to maintain the environment of the ill and the aged at even more elevated temperatures than are usual for active persons. This is a special situation where microwave radiation might play an important role, not only by bringing about net savings of energy but by making it possible for others to remain comfortably in the same, otherwise overheated, environment. Clothing made with metallized threads could serve to screen out the radiation, mainly reflecting it, thereby reducing its effects on such active occupants.

The question of whether there are nonthermal effects that must be considered in the interaction of microwaves with tissue is a subject of debate. It is perhaps worth noting that microwave radiation contains only photons whose quantum energy is very much smaller than the mean energy of the pervasive thermal agitation and vibration of individual atoms and molecules of all matter at temperatures supportive of life. Microwaves form a part of the spectrum of radiations emitted by all objects at temperatures above about 1 K, and are present in the radiation from the sun. These photons, individually, have none of the penetrating and disruptive qualities possessed by gamma rays, x-rays, or energetic particles encountered in nuclear reactions.

The Group on Microwave Theory and Techniques, of the Institute of Electrical and Electronics Engineers, in 1971 devoted an issue of their transactions to the subject of the biological effects of microwaves. It seems that even advocates of the view that there are dangerous nonthermal effects accept the argument that the shallow penetration of 3-cm and shorter microwaves makes them unsuitable for use in testing for such effects (*3*). It is worth noting here that at short microwave wavelengths the penetration depth in tissue with a sizable water content is proportional to the square of the wavelength (*4*). With the principal warming occurring in the skin, it seems likely that there is little difference between being warmed by such microwaves and being warmed by more conventional infrared waves of, say, 100-μm wavelength. No great danger has been cited from the radiation from a fire on the grate or a stove. These traditional devices, as employed mainly prior to the spread of central space heating, did tend to be used to deliver heat to persons relatively more than to raise the temperature of the space itself, but most of them were highly inefficient and nonuniform.

Some fear of this proposed form of heating might arise from the association with microwave ovens for cooking. Of course, that application of microwaves makes use of the same ability to heat the desired object, with the development of very little heat in the air or the walls of the enclosure. However, wavelengths of 12 cm or more are used in ovens, and these penetrate more than ten times more deeply than does 3-cm radiation in tissue with a sizable water content. Also, cooking is a matter of degree. All forms of domestic heating have their counterparts in cooking, when the level of the heat is made sufficient. One may associate, for example, forced hot air (or a dry sauna) with baking, a damp sauna with steaming, and radiant heat with broiling. The open fire itself is also used for broiling, but that does not prevent a fireplace from serving as a pleasant source of warmth. The important factor in all cases is the limitation of the exposure to an appropriate level.

R. V. Pound

Lyman Laboratory,
Harvard University,
Cambridge, Massachusetts 02138

References and Notes

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2. J. Edrich and P. C. Hardee, *IEEE Trans. Microwave Theory Tech.* **MTT-24**, 273 (1976).
3. A. H. Frey, *ibid.* **MTT-19**, 153 (1971).
4. See, for example, H. P. Schwan, *ibid.*, p. 146.

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The Double Quasar 0957+561: Examination of the Gravitational Lens Hypothesis Using the Very Large Array

Abstract. *A full 12-hour synthesis at 6-centimeter wavelength with the Very Large Array confirms the major features previously reported for the double quasar 0957+561. In addition, the existence of radio jets apparently associated with both quasars is demonstrated. Gravitational lens models are now favored on the basis of recent optical observations, and the radio jets place severe constraints on such models. Further radio observations of the double quasar are needed to establish the expected relative time delay in variations between the images.*

One of the classic consequences of general relativity is the bending of light rays by the sun's gravitational field. A star's image is displaced outward by an angle $2R_s/b$, where R_s is the sun's Schwarzschild radius and b is the distance of closest approach of the ray to the center of the sun (the impact parameter). Einstein and others recognized that a corresponding gravitational lens effect might be seen in more distant astronomical objects [see Refsdal (*1*)]. A massive intervening object (the "gravitator"), so compact that it might act effectively as a point mass, would create two images of any object behind it and nearly on the same line of sight. The primary image is displaced outward from the gravitator with respect to the undeflected position of the object, while the weaker secondary image appears on the opposite side of the gravitator. The primary and sometimes (depending on the geometry) the secondary image is amplified by the lens effect. As the angle between gravitator and object is increased, the primary image and object merge, and the secondary image fades out. The more complicated gravitational lens properties of extended mass distributions can result in more (or fewer) images, and have been treated by Bourassa and Kantowski (*2*), Krolik and Kwan (*3*), and others.

Walsh *et al.* (*4*) discovered that the twin quasars associated with the radio source 0957+561 were so similar in their optical properties that they might well be an example of the gravitational lens effect. The A and B quasars, A being northernmost, exhibited emission-line and absorption-line redshifts that were identical, within their measurement accuracy. Their results have recently been confirmed by the higher resolution observations of Weymann *et al.* (*5*). If time variations could be neglected, the near equality of the fluxes implied that the gravitator and object quasar were aligned to within 0.3 arc sec and that the gravitator was within 0.1 arc sec of the midpoint of the line joining A and B. Assuming a conventional Friedmann cosmology, the 6 arc sec separation of the quasars and their redshift (z_{em} = 1.4) implied a massive gravitator ranging from 2×10^{11} solar masses ($M_\odot$) (the mass of a typical galaxy) to 2×10^{14} $M_\odot$ (more massive than any known galaxy) depending on the distance of the gravitator.

Gravitational refraction should be frequency-independent, so radio measurements were immediately undertaken in an attempt to verify the double-image hypothesis. The first radio maps were made at a wavelength of 6 cm by two groups. Pooley *et al.* (*6*) used the Cambridge (England) 5-km telescope, with 2 arc sec resolution, and Roberts *et al.* (*7*) used the Very Large Array (VLA) of the National Radio Astronomy Observatory, with 0.8 arc sec resolution. With one small exception, the maps agreed in their main features. Both maps showed the A and B quasars, with intensities very similar in ratio to that observed optically. Since the frequencies differed from the

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