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Some aspects of the utilization of natural radiation, especially in the developing countries

Energy requirements vary considerably from one part of the world to another, and depend on a number of factors relating to human societies and their activities: climate, living and working conditions, basic needs of daily life, needs arising from scientific, industrial, economic and social development and so on.

In countries with a high industrial and economic potential, the energy factor is the essential basis of a continuously expanding and even more multifarious material civilization. Energy consumption per inhabitant is growing apace and the majority of human activities depend on it.

The human societies called 'civilized' from the material standpoint possess a host of mechanical, electrical, electronic, thermal and other 'slaves' which enable them to act and operate in extraordinarily diverse and effective ways.

In these countries with a high potential, the earth's reserves of conventional energy—coal, oil and natural gas—are being more and more heavily drawn upon, while the immediately available forms of energy, such as heads of water, are being used to the maximum. The present situation is extremely promising, for intensive prospecting of the soil and underlying strata of the earth reveals great opportunities for the use of coal, liquid fuel and natural gas reserves.

At the moment, there is even an overproduction of various fuels, and in certain cases new deposits are not exploited because of the uncertainty of finding markets for them.

There remain perhaps a few hundred years' supply of oil and a thousand years' supply of coal, but that is sufficient to give an optimistic touch to energy prospects, especially as nuclear energy with its enormous possibilities is appearing on the horizon.

This, of course, does not prevent keen world-wide competition and vigilant concern for these terrestrial capital reserves which, as consumption trends show all too clearly, cannot be replaced at the same rate by natural processes even now, let alone in the face of future demands.

As matters stand today, the use of the so-called 'secondary' or replacement sources of energy, which include solar energy and in which we also class

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terrestrial energy, is not, of course, a problem requiring urgent solution. It is with these forms of energy, however, that we shall be dealing in this article. For, in addition to the materially highly civilized societies which occupy only a relatively small part of the earth's surface, we must also take account of the huge majority of the world's population, spread over vast territories from the Poles to the Equator, including, in particular, what are usually called the arid zones.

In general, these peoples are poorly supplied with energy either because they have not yet developed local resources of conventional energy or because, having no such resources, they are economically unable to replace them with sufficient supplies of transportable fuel, of which, incidentally, there is considerable overproduction in other parts of the world.

Inadequate purchasing power is not alone to blame. Distance and, in some cases, the absence of economic means of transport substantially increase the price of conventional fuel delivered to certain areas.

It is from this angle that the use of substitute forms of energy should be considered. At the present stage, the use of these substitute forms for industrial purposes is out of the question except perhaps in very special cases. For example, solar furnaces, the use of which for fundamental research and for certain special applications is developing along hopeful lines, can only be introduced at this juncture in a very limited manner in certain countries with unclouded skies; they could play only a very small part in 'settlement policies' for the settlement or development of communities in the arid zones.

It is with the object of improving physical living conditions in already existing communities that the energy from natural (solar and terrestrial) radiation should be put to use.

In many regions where the sky is very clear (whether near the tropics or much farther north or south), the inhabitants suffer from extremes of heat or cold. At certain periods they lack water, especially pure water; they lack power for the operation of cottage industries, and refrigeration to preserve food and pharmaceutical products. They also lack means of transport, communication and information. To all these problems, interesting possible solutions, some more economically profitable than others depending on their practical nature, might be found in the use of energy from natural radiation.

EXPLOITATION OF SOLAR RADIATION

Space heating in dwelling houses

In many cloudless countries it is warm or hot during the day and sometimes very cold at night. Even in low latitudes—for example, in the Sahara—the winter season is cold above a certain altitude. In Afghanistan the average temperature over twenty-four hours is relatively low during the greater part of the year owing to the very low night temperatures. In the arid regions indoor comfort could be much improved if even a fraction of the solar energy accumulated during the day were to be trapped and stored.

In France, the National Centre for Scientific Research (CNRS) has been working to find an economic solution to this problem. Prototype houses have been built, with significant results.

The principle consists in capturing the solar energy received by the southern façades of these houses. As is well known, the energy from solar radiation in cloudless countries amounts to about 1 kWh./m.^{2} on a surface placed at right angles to the sun's rays. The total energy received on a southern façade has been calculated for different latitudes (F. Trombe, A. Le Phat Vinh and Mrs. M. Le Phat Vinh). Figure 1 summarizes the readings for the northern hemisphere. For the southern hemisphere, identical curves would be found for the corresponding seasons.

An examination of Figure 1 shows that the insolation curve for southern façades in latitudes between the tropics and the neighbourhood of 60° is parallel to the curve for house-heating requirements. The sun being very high in summer, southern façades receive little sunlight; indeed, at the Tropic of Cancer they receive none at all in June. In any case, protruding roofs over southern façades protect them very effectively from the direct rays of the sun for several months of the year, sometimes even for more than six months.

In the period between October and March, which may be cold, the sun is much lower, and the amount of sunshine on the southern façades reaches its peak. Examining Figure 1, we see that the total amount of energy theoretically received during the winter solstice ranges around 7 kWh./m.^{2}/day.

This is equivalent to what is received by the roofs of houses in summer when the aim is rather to get rid of the sun's heat.

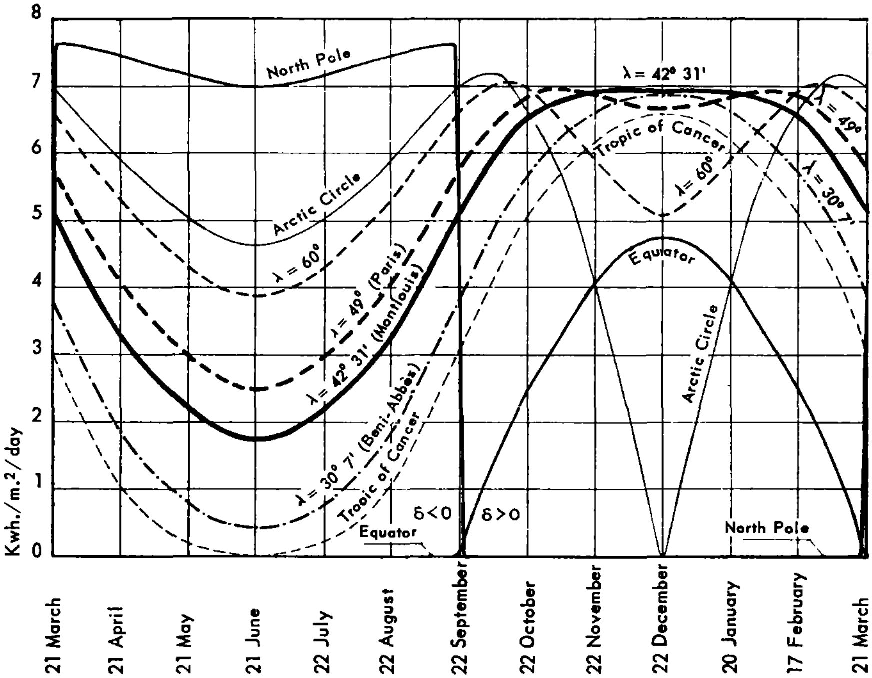
The reception of solar energy on southern façades, which is particularly suitable for the heating of houses, makes it possible to capture large quantities of solar calories, amounting in cloudless countries to 80 or 85 per cent of the theoretical total (see Fig. 1). Under average conditions, a southern façade actually receives from 5 to 6 kWh./m.^{2}/day. For a single-storey dwelling this represents several hundred kWh. per day, the bulk of which can be retained indoors.

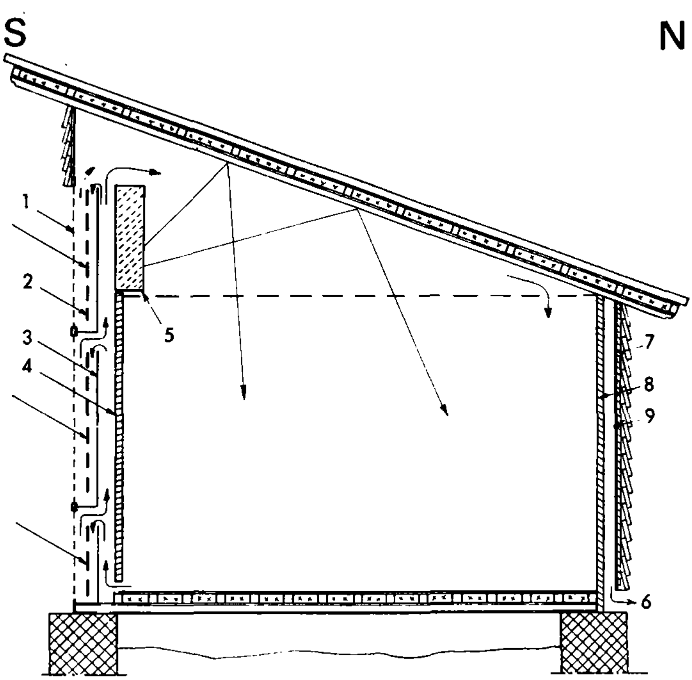
It should also be noted that a glass-surfaced façade, being vertical, costs less than a glass roof. A glass roof must perforce be weatherproof, and mechanically strong enough to support an accumulation of snow, in mountainous areas for example. Furthermore, the accumulation of snow on roofs seriously reduces the solar input and the glazed surface may cease to have a hothouse effect for extended periods of time. A further disadvantage of glazed roofs is that they supply calories only to the upper sections of the house.

On the other hand, the advantages of south-facing glazed walls are readily appreciable. The glass used can be lighter in weight and still remain comparatively weatherproof, since it does not have to withstand the direct force of atmospheric precipitations. In addition, the height of the glazing can be extended as far upwards as is desired, thus enabling multi-storeyed buildings on an east-west axis to be equipped with solar collectors.

It may be objected that southern façades should be sources of light, and that the capture of calories by means of blind surfaces could result in the

Fig. 1. Solar energy received on a southern façade in the northern hemisphere.





1 Glass
2 Collector
3 Protective panels
4 Heat-resistant wall
5 Water storage tank
6 Circulating air
7 Insulating layer
8 Heat-resistant wall
9 Infra-red reflector

Fig. 2. Unit-construction dwelling with built-in solar heat collection and storage system.

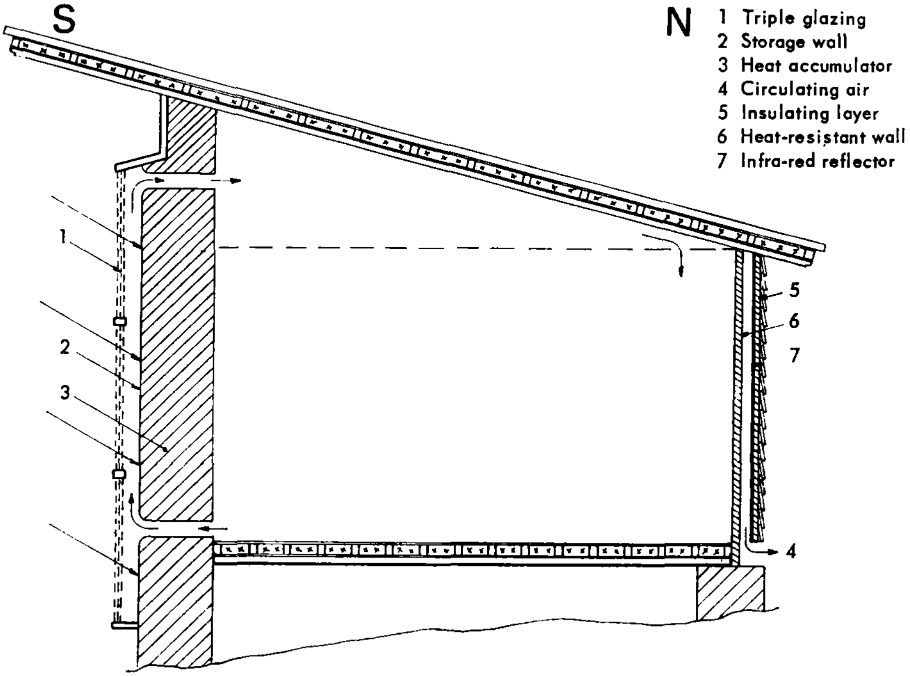


Fig. 3. Prototype of unit-construction dwelling with solar heat collector and thick ground-to-roof storage walls (CNRS, Montlouis).

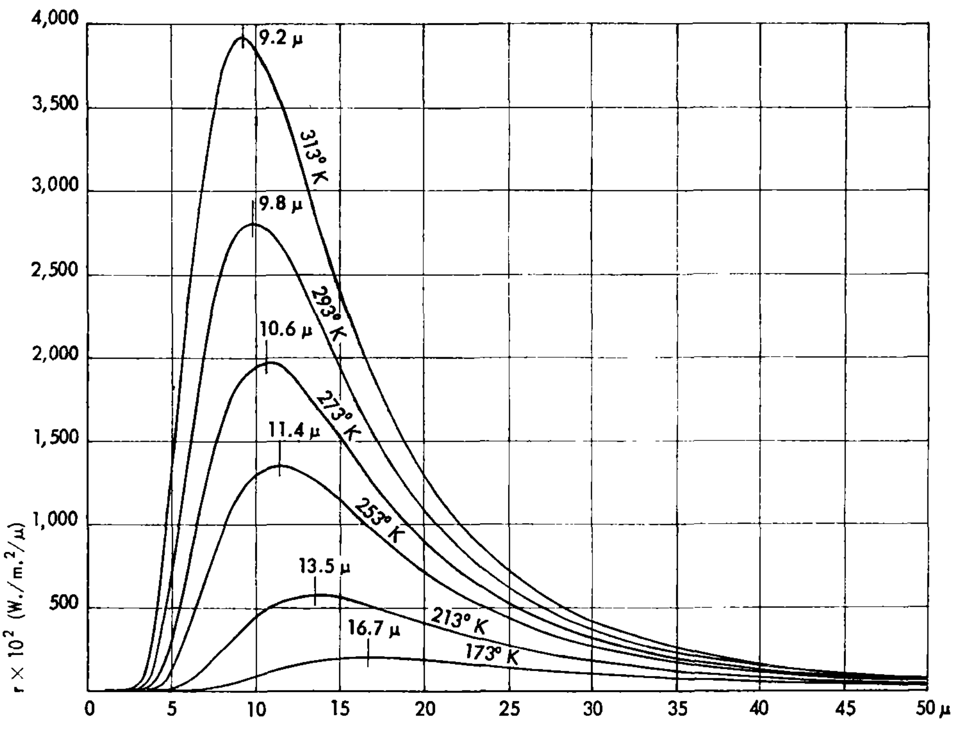


Fig. 4. Black body radiation.

construction of poorly-lit buildings. Experience shows, however, that in cloudless countries only one-fourth of the surface of a south wall of a room of normal dimensions is used to admit light, the other three-fourths being opaque surfaces which admit neither light nor calories.

The diagram in Figure 2 shows a unit-construction house into which is built a low thermal mass in the form of a water tank (5) running east and west across the south wall.

The solar energy passes through a glass surface (1) and heats the collectors (2) which emit warm air through the main duct situated behind a wall (4).

By means of this upward flow of air, a well-balanced temperature is obtained over the entire height (approximately 3 metres) of the living area. At night, the protective panels (3) surrounding the collectors help to prevent the air cooled by contact with the outside glass walls from descending into the living area. The water mass (5) located above the living area restores calories to that area by radiation, both directly and by reflection from the ceiling which is lined with infra-red reflecting aluminium foil.

This dwelling with a floor area of 80 square metres has a storage tank containing approximately 7 cubic metres of water giving back about 50,000 kilocalories during the night. This storage capacity is obviously insufficient, and to obtain adequate results a thick wall extending from ground to roof level would be needed. Such a wall will be incorporated in the prototype (Fig. 3) now being built at Montlouis-Odeillo (Pyrénées-Orientales) in France.

In addition, on the north, east and west sides the dwelling shown in Figure 2 has specially designed walls for the selective capture of calories. The main insulating wall is protected on the outside by an air space, an infra-red reflecting surface (9) and another heat-insulating layer (7) consisting of two thicknesses of boards, the second of these being largely decorative in function.

This wall serves as a warm air trap, discharging in the daytime the colder-than-outdoor air which it contains, and retaining at night, to some extent, the warm air accumulated during the day.

The very important role of the polished aluminium foil infra-red reflector (9) should be stressed. It is well known that radiation losses are much greater than convection losses, even at normal temperatures.

In its present form, this type of dwelling becomes a little too hot during the day (30° C.) and a little too cool at night (8° to 10° C.). But apart from this drawback, which is due to the inadequacy of the interior thermal mass, it behaves very differently from ordinary houses in Montlouis which always freeze hard in winter. It should be noted, in fact, that the mean temperature of the outer surface of a dwelling, and consequently, *a priori,* its inside temperature, may be well below the mean temperature of the ambient atmosphere, especially if there is no intake of solar energy (as in the case of north façades) and if the night sky is clear.

Finally, we should note that this type of dwelling provides warm air not only on sunny days but also on days when there is bright cloud. This is due to the direct angle of incidence of the sun's rays on its south-facing glass wall, and indoor temperature rises of over 10° C. on cloudy days are quite common.

The present programme of the CNRS includes the construction of various dwelling houses, along the lines of Figure 3, with heat storage walls to keep the temperature below the daytime outside maximum (30° C.) and take the chill of the dawn temperature (8° to 10° C.).

It should be stressed that such dwellings require no costly apparatus; for instance a four-roomed house (80 square metres total floor area) built by conventional methods costs some 65,000 French francs; the same building with incorporated solar collectors and accumulation wall as shown in Figure 3 would cost 75,000 to 80,000 francs.

The thermal kWh. thus reclaimed works out very cheaply. If we estimate the total cost of the collecting installation at 15,000 francs, covering a surface area of 64 square metres (16 × 4 m.), for a four-roomed house, we arrive at a yearly amortization rate of 750 to 800 francs.

Assuming that the installation operates for six months of the year and taking into account exceptionally warm and sunless periods, the heat energy collection would amount to 5 kWh. × 64 × 180 = 57,600 kWh. The solar kWh. thus obtained therefore costs less than 1.5 centimes, which is very cheap indeed.

Refrigeration

The use of solar radiation for refrigeration is one of the most intriguing prospects for the improvement of living conditions in countries with clear skies.

A great deal of research has been done on this subject in France, the Soviet Union and the United States. Hitherto, the cost of ice produced by solar energy has been substantially higher than the cost of ice produced by conventional methods. The cheapest ice so produced appears to be that made at the French (CNRS) plant at Montlouis which operates on the principle of direct distillation by day and expansion of ammonia gas at night. The cost per kilogram is between 0.10 and 0.15 francs. This is more than double the current price in large urban centres, for example on the African coast. On the other hand, at inland centres current prices are much higher, and here solar ice might well be competitive with that produced by conventional means. The possibilities of such production are now being investigated.

Water heating

Heating water by means of the sun's rays and the hothouse principle is a highly economic operation. The hothouse is very simple, and many versions of metal and glass, or plastic, water heaters have been constructed in the United States, in Israel and especially in Japan, where hundreds of thousands of them have been installed.

Water distillation

A supply of pure water is a vital necessity for any settlement area, and the absence of such supplies is the main obstacle to arid zone development.

Many excellent solar stills have been developed in France, Algeria, Australia, the United States, the Soviet Union and Israel. The production of fresh water from brackish water by solar processes is fairly expensive, and it would seem to be no easy matter to lower the cost, which is about 1 to 2 francs per cubic metre.

To distil one litre of water over 600 calories are needed, which is more than is needed to smelt one kilogram of iron. As things stand at present, solar water may be very useful for human drinking purposes, but it is a little too dear for cattle and out of the question for crop irrigation. It seems that the development of small-scale solar stills is to be preferred to the establishment of large distillation plants.

Motive power

A basic community requirement is some form of energy for pumping water and generating electricity.

Extensive research in France, the United States, the Soviet Union, Israel and Senegal has led to the development of various kinds of solar generators. The general conclusion is that under the present competitive conditions governing energy production, the solar engine is still too expensive and cannot compete with liquid fuel, even in remote areas. However, in view of the importance of the problem, it is essential to encourage the introduction of prototypes in various countries so as to see how they stand up to operation under actual working conditions and to devise a standard type of solar generator for which there is certainly a promising future both as a technical and as an economic proposition.

Other applications

There has been much talk of devices for cooking food by solar heat in regions where there is plenty of sunshine but no other energy resources. Although those tried out in India and Latin America have not been successful, there is no reason why the effort should be abandoned. The main thing is for the manufacturers of solar cookers to discover solutions which are economic —which is certainly possible—and, above all, practical, taking due account of the customs of the populations concerned.

Another application of solar radiation which should be developed is the use of photopiles and thermopiles.

Photopiles could be used to very great advantage to feed transistor equipment used for public and private telecommunication purposes. Thermopiles could be used not only for these purposes but also for operating small-capacity refrigerators (Peltier effect) to preserve certain products, such as medical supplies.

EXPLOITATION OF TERRESTRIAL RADIATION

It has long been known that in cloudless areas and at night the earth's surface is always colder than the surrounding air. The difference in temperature is not very high at any given moment—2° to 6° C., and in exceptional cases as much as 8° to 9° C.—but it is nevertheless responsible for widespread phenomena (extensive cooling of the earth's surface and the air during the night, dew and hoar-frost). All these are due to a considerable loss of infra-red energy by the earth to the atmosphere and to space. This loss of energy, which many experimenters since Angström and Boutaric have measured, may amount, in clear and dry weather, to more than one-third of the earth's total radiation at the given temperature; for example, the earth, considered as a black body, would radiate 316W./m.² at 0° C., whereas it would receive only about 200 W./m.² from the atmosphere. This difference of more than 100 W. is not exclusively due to the fact that the emitting atmosphere is colder than the earth (which, incidentally, is not always true): it is due to the discontinuity of the atmospheric spectrum.

Figure 4 shows black body radiation (the earth's surface is almost black) at different temperatures, as a function of the wave-length expressed in microns.

Figure 5 shows the transmission spectrum of the atmosphere and the largest transparency zone or slot between 8 and 13 μ. It is mostly through this slot that the escape of terrestrial energy takes place beyond the atmosphere into space.

An attempt was made at the Montlouis Laboratory (by F. Trombe, A. Le Phat Vinh and Mrs. M. Le Phat Vinh) to exploit this phenomenon to obtain cold or refrigeration—in other words, to localize energy losses in order to obtain regular and much larger drops in temperature than those which are to be observed in nature.

The principles applied are extremely simple (see Fig. 6). The black body (1), the temperature of which is measured at (2), is placed at the bottom of an insulated box (5) lined on the inside with an infra-red reflecting metallic surface (4), for example, non-oxidized aluminium or a polished gilt surface. The outer wall of the device is of the same nature as the emitting surface (1), for example, oxidized aluminium or glycerophthalic paint containing titanium oxide (rutile). The box thus prepared can be surrounded by a reflecting screen at (8) and a radiating body (like 1 and 6) at (7) for daylight tests.

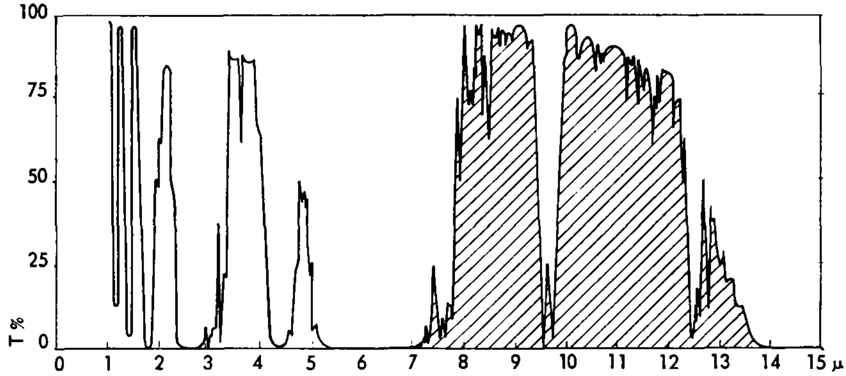
A problem which arose, and which was solved only after considerable research, concerned the lid of the box (3), which has to have the same transparency zones as the atmosphere. Polyethylene 50 to 200 μ in thickness was finally adopted on account of its extreme transparency in the principal atmosphere slot (see Fig. 7).

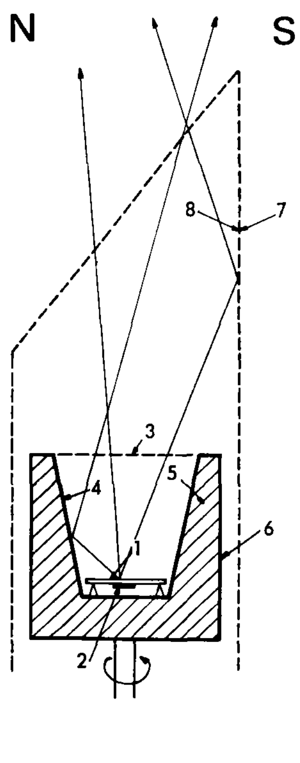
The results obtained with this simple apparatus are spectacular; *a stable temperature drop of 14° to 30° C. in relation to the surrounding air.*

Results of this kind can be obtained either in the daytime or at night, provided that the reflecting and protective screen (7, 8) is employed and that a selective radiating substance is used as radiator (1)—a black body for infra-red to reflect the sun's rays diffused by the sky (radiation below 1 μ).

An additional 4° to 7° C. can be gained by the use of concentric boxes (Fig. 8), which serve to attenuate the losses by conduction. The temperature

Fig. 5. Transmission spectrum of the atmosphere ; principal transparency slot.

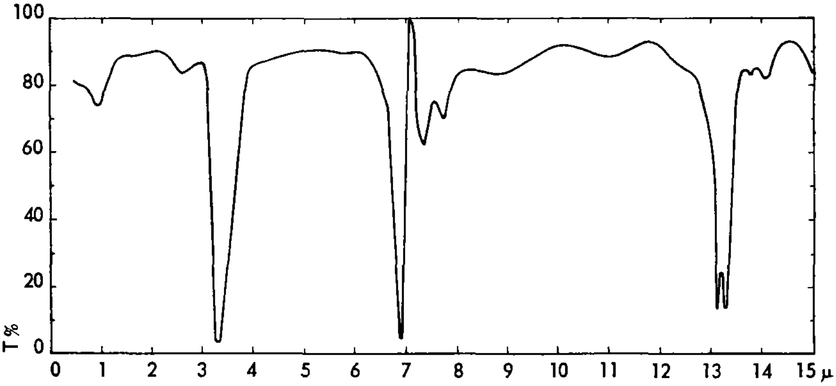




1 Black body
2 Temperature recorder
3 Lid of box
4 Infra-red reflector
5 Insulation
6 Radiating surface
7 Protective screen
8 Reflecting surface

Fig. 6. Experimental localization of energy losses.

Fig. 7. Transparency of polyethylene 50 μ in principal atmosphere transparency slot.



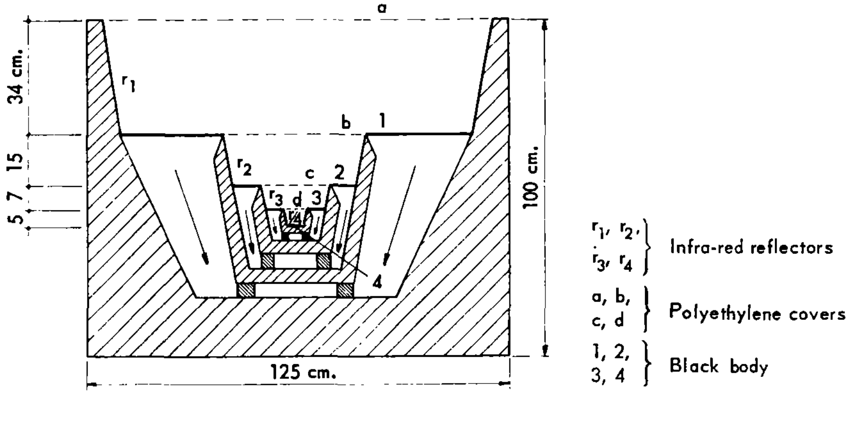


Fig. 8. Concentric box system of attenuating conduction losses.

drop then ranges from 18° to 36° C., depending on the transparency of the sky.

In our experiments we have used a very wide variety of radiating substances: silvered glass, oxidized aluminium, any type of metal surface with a suitable coat of paint, and even a plastic surface (polyvinylchloride) presenting an emission spectrum in the 'window' zone in which polyethylene is transparent.

Had they not been repeated very many times and strictly controlled in every detail, these experiments might have met with considerable incredulity on account of the magnitude of the drops in temperature that were recorded.

Experimentally, in fact, temperatures are found which are often lower than those obtainable by calculation on the basis of the energy emitted per unit of surface at the temperature of the surrounding air, but this phenomenon is easily explained by the discontinuity of the spectrum emitted by the atmosphere.

It is quite evident that phenomena of this nature, which occur over the greater part of the earth's surface and practically dictate the climate of the earth's environment, call for thorough basic studies whose practical significance should not be overlooked.

Air-conditioning of houses

It is now possible to modify considerably the average temperature of living premises in arid zones and to establish a climate in which normal living conditions can be obtained.

In addition, there is the fact that the moisture content in the very dry air of arid zones is still relatively low when the air has been cooled down to around 20° C. This means that to the radiation effect a further cooling effect can be added by saturating the air with water vapour, the air being used to accumulate cold in thermal masses instead of directly in the dwelling.

Cold rooms

The exploitation of Δt (drops in temperature) during the night period, which is relatively cold in cloudless countries, should in most cases result in temperatures in the neighbourhood of 0° C., or possibly lower than 0° C. with the application of an additional refrigeration effect produced by vapourizing water or dissolving certain salts. It would thus be possible to ensure stable temperatures of between 0° and 10° C. day and night in heavily insulated compartments constituting veritable cold rooms.

This possibility opens up very considerable prospects for the conservation of foodstuffs (meat and even fruit) which deteriorate very quickly in hot countries.

Energy production

It is also important to be able to have a stable Δt of 15° to 30° C. day and night.

Frequent attempts have been made to operate large thermal cycles with a Δt of the same order, necessitating the use of expensive apparatus. The evidence is that radiation towards space could lead to a form of production of energy through the functioning of thermal cycles which could be very simple and which would in any case be useful for the day and night feeding of the cold source of thermopile groups.

Condensation

Finally, it is not impossible that such temperature differences would enable large quantities of water to be condensed underneath the radiating system independently of the polyethylene screen.

CONCLUSIONS

From this quick survey of the possible uses of energy obtained from natural radiation with particular reference to the developing countries, we may list a few conclusions.

1. There are applications of solar and terrestrial energy which can already be exploited economically; for instance, house and water heating can be envisaged in cloudless countries where there are long periods of sunny cold weather. Afghanistan, for example, has such a climate.

In warmer parts, such as the African regions from North Africa to the Sahel, the main problem is the production of cold. As from now it is possible to envisage applications of terrestrial radiation which could improve living conditions in dwellings and be used to preserve food.

In general, in cloudless countries with extreme conditions (hot in the day and cold at night, with great variations in average temperatures throughout the year) sources of both heat and cold are needed according to the season.

Other uses of solar heat for the distillation of water or desiccation of fruits, for example, also offer interesting possibilities. One great problem is that of providing fuel for the cooking of food which is a serious cause of deforestation in regions already poor in vegetation.

Despite many interesting attempts it has still not proved possible to introduce solar cookers in countries where there is abundant sunshine. The effort to be made in this respect is both technical and psychological, and the solution lies in convincing populations bound to ancestral methods to change their habits.

2. There are other applications which deserve attention, such as refrigeration by thermal cycles, the heat being provided by solar energy. We have seen that ice production by this method could compete, in countries where fuel is expensive, with conventional methods of production. Such economic feasibility, however, could not be achieved with individual household freezers but only with community plants producing ice for a population equivalent to that of a small village.

3. Other applications of solar energy will have this importance in the future but cannot as yet be considered as paying propositions. These include the production of motive power for pumping water and generating electricity. The small individual plant is as yet much too expensive, while power production in large solar generating stations still works out at too high a cost per kilowatt. But these disadvantages should only be considered spurs to further research in this field of importance.

How can we now envisage the gradual promotion of the use of natural radiation energies?

The first step is to install publicly-operated plants with the help of governments and possibly international organizations. Little by little, thanks to such concrete examples and accumulated experience of actual working conditions, private ventures will follow.

With regard to those uses of radiation energy which, while already technically feasible, are still generally inapplicable for economic reasons, one can only hope that every effort will be made to develop devices of various kinds and that prototypes of these will be put into service in the actual locations where their future utility will be most valued. Here again international co-operation in both research and practical development will be required.