Lawrence Berkeley National Laboratory

Recent Work

Title

NOTES ON PRACTICAL MATERIALS FOR THERMAL INFRARED RADIATIVE COOLING SYSTEMS

Permalink

<https://escholarship.org/uc/item/6jv5w20c>

Author

Berdahl, P.

Publication Date

1979-08-01

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

NOTES ON PRACTICAL MATERIALS FOR THERMAL INFRARED
RADIATIVE COOLING SYSTEMS

Paul Berdahl

August 1979

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782*

RECEIVED
LAWRENCE
BERKELEY LABORATORY

OCT 15 1979

LIBRARY AND
DOCUMENTS SECTION

LBL-9735 C.2

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

NOTES ON PRACTICAL MATERIALS FOR THERMAL INFRARED
RADIATIVE COOLING SYSTEMS

Paul Berdahl

Energy and Environment Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California

Notes on Practical Materials for Thermal Infrared Radiative Cooling Systems*

Paul Berdahl

Energy and Environment Division
U.C. Lawrence Berkeley Laboratory
Berkeley, California 94720

Unfortunately, the state of the art of using the resource for radiative cooling by infrared transfer to the sky is quite primitive. This is in contrast to the other passive cooling techniques of evaporation, convection, and ground cooling. The only well-known natural or passive cooling system which obtains a major portion of its cooling from I.R. transfer is the celebrated Skytherm system invented by Harold Hay. One practical obstacle to the development of radiative cooling systems is that the properties of materials in the infrared spectrum are often quite different from the corresponding properties in the visible spectrum. To assist people who might consider the use of infrared cooling, I have written a short essay on relevant materials properties. Please consider these notes as merely a starting point---a serious investigator will want to look into further references, such as The Infrared Handbook published by the Environmental Research Institute of Michigan.

1. The Cooling Effect

Any object emits infrared radiation in the wavelength range 5 to 40 microns. (A micron is one-thousandth of a millimeter. One (English) mil is equal to 25.4 microns.) An ordinary object at 293 degrees Kelvin (20 degrees Celsius) emits 418 watts per square meter, if it is infrared black. A surface which is not infrared black does not emit quite so strongly. For example, a clean metal surface may have an infrared emissivity of only 0.1, compared with 1.0 for a black surface, and can emit only 10 per cent as much radiation, or 41.8 watts per square meter at 20 degrees Celsius. Clean metal surfaces are practically the only common

* This work has been supported by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, U.S. Department of Energy under contract No. W-7405-ENG-48.

materials with low infrared emissivities. For example, optically black and white paints are primarily black (emissivity = 1.0) in the thermal infrared part of the spectrum of interest here. Liquid water, glass, and most plastic surfaces are also quite black.

In choosing a material for the radiator portion of an infrared cooling system, surfaces with a large emittance are naturally desired in order to maximize the energy transfer for cooling. However, surfaces absorb infrared radiation from their surroundings as well as emitting it. (Thermodynamics requires that the I.R. absorptivity equals the I.R. emissivity.) The cooling effect is possible only when the rate of absorption is smaller than the rate of emission. Under "normal" circumstances of thermal equilibrium (say, in a room which is all at the same temperature), the net energy transfer to and from a surface balances out regardless of the type of surface. This balancing is a consequence of the second law of thermodynamics, which forbids an object to spontaneously warm up or cool down without a source of energy. On the other hand, if a surface is exposed to the night sky (or the day sky if it has a very high solar reflectivity), it will cool down due to the "weakness" of the thermal infrared radiation from the sky. Under such circumstances, an infrared-black surface will cool much more effectively than a surface with a small emissivity such as a metal. The cooling effect is larger for surfaces mounted horizontally than it is for inclined surfaces (ignoring possible effects due to sunlight), and it is larger when the sky is clear rather than cloudy.

This process of infrared cooling may seem rather mysterious, but it is nevertheless quite commonplace. Infrared cooling is one of the primary mechanisms which permits the ground to cool off after being heated by the sun each day. Not only is the ground cooled, but the roofs of houses and buildings are cooled in the same manner. The effectiveness of this resource for cooling, however, is diminished by contact with the warmer ambient air, and the "coolness" is also usually excluded from the building by the thermal design of the structure. The problem of reducing the convective intrusion of heat from the ambient air requires the construction of "windcreens" which restrict the free flow of air while allowing the thermal infrared rays to penetrate freely. A properly designed windscreen can have a second advantage---it can be used to reflect the sun's rays.

In summary, an ideal infrared radiative cooling system would have a radiator which is reflective in the solar spectrum (visible and near infrared) and emissive or black in the thermal infrared region. A high performance system, such as some systems being studied at LBL, might utilize a "selective" radiating surface which is reflective in portions of the infrared spectrum and highly emissive in

others, in order to produce higher cooling rates at low radiator temperatures. In addition to a radiator, an ideal cooling system should have a windscreen which is transparent to thermal infrared rays but which is reflective in the solar spectrum. Of course, any real system would not have every desirable feature. For example, a system might be intended to cool only slightly below ambient and thus not be provided with a windscreen. Or, the radiator surface used might be visually black, the designer having abandoned the prospect of getting useful cooling during the day.

2. Some Practical Radiator materials.

Since most common building materials and paints are infrared black, and thus suitable for use as radiators, other considerations may dictate the choice of material. For example, if the radiator is to be exposed to the sun, it should have a high solar reflectivity. Ordinary light colored paint or whitewash are suitable choices. There are also commercially available paints specially formulated for high solar reflectivity. A clean aluminum surface with a coating of an infrared-opaque plastic would also work, with the plastic coating protecting the aluminum from the oxidation processes which normally reduce its solar reflectivity after a time. The combination of aluminum plus Tedlar (Du Pont tradename) works this way, with the added feature that the partial transparency of Tedlar(i.e., the "non-blackness") in the thermal infrared range actually improves (1) the radiative cooling effect at low temperatures. Thus this combination should be considered if one wishes to cool, say, 10 degrees Celsius or more below ambient. A transmission spectrum for Tedlar is included in Figure 1.

It's worth emphasizing that glass and water are completely black in the thermal infrared spectrum, and thus make good radiators. By the same token, glass cannot be used as a glazing material; it is completely opaque. More than one experimenter has discovered, to his chagrin, that a solar collector with glass glazing will provide little or no cooling. Also, note that if temperatures in the cooling system become as cold or colder than the dew point, condensing water can interfere with the infrared radiative transfer.

As mentioned above, almost anything can be used as a radiator. Exceptions to this rule are clean metal surfaces (which are good infrared mirrors), and the handful of materials that are infrared transparent, which is the subject of the next section.

3. Windscreen materials

The two essential properties which a windscreen must have are that it must be transparent in the thermal infrared spectrum, and it must be strong enough to support itself. These two requirements seem to limit the field to a single practical material. Polyethylene. In thicknesses from 10 to 100 microns (0.4 to 4 mils) polyethylene has a spectrally averaged transmissivity of approximately 80 percent. The transmission does not depend much on thickness because the absorption which occurs in narrow bands at 3.4, 6.8, and 13.7 microns is quite strong even in thin layers and thus cannot increase much in thicker layers. See Figure 1. The transmission does however depend on purity. Polyethylene can contain a number of additives (e.g. silicone, a lubricant) which can interfere with the infrared transparency. The only way to be absolutely certain about the infrared properties of any sample is to test it with a spectrometer.

There are a few other materials which are transparent in the thermal infrared spectrum, which may find eventual use in infrared cooling applications. Most of the semiconductors are infrared transparent, and have the added advantage that they often reflect the solar spectrum. Examples are silicon, germanium, and cadmium sulfide. Carbon is "almost" a semiconductor and is in fact quite transparent in the form of small particles. Tellurium is yet another near semiconductor which could in principle be used as a windscreen material.

In addition to the semiconductors, there are a number of polar (ionic) materials, such as the alkali halides, which tend to be transparent in the infrared. These materials are generally transparent in the solar spectrum as well. Some examples are sodium and potassium chlorides, potassium iodide, thallium chloride, and cesium iodide. It's interesting that ordinary rock salt is in this class. Unfortunately, these materials tend to be water soluble, and even hygroscopic. Perhaps a way to use them can be found.

Since polyethylene is the only easily usable material available for windscreens, current developments in this area use polyethylene as a support matrix in which a solar reflective material is dispersed. One approach is to use titanium dioxide particles suspended in polyethylene. An Italian group has pursued this angle. (See the paper by Addeo et al. in the Passive Materials and Innovative Systems Session of the May meeting of ISES in Atlanta---Proceedings should be out soon.) Small particles of titanium dioxide are efficient reflectors of solar radiation; they are used as the pigment in most white paints. A thin layer of this material in the form of small particles can still permit a moderately good infrared transmissivity. A bonus to this approach is that the solar reflectivity can help protect the

polyethylene layer from ultraviolet damage. A French physicist has experimented with thin tellurium coatings, to be applied to polyethylene, to accomplish the same goal. A brief writeup of his work is available in French (Ph. Grenier, in Revue de Physique Appliquee, Vol.14, p.87, (1979)).

Fig. 1 Polyethylene and Tedlar Transmission as a function of Wavelength.

XBL 798-10766

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720