HEAT FLOW BY RADIATION IN BUILDINGS
SIMPLIFIED PHYSICS

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PREFACE

If a building is uncomfortably cold in winter; or uncomfortably warm in summer; or if the cost of fuel is excessive; then the architect engineer, builder, heating contractor and insulation applicator will all be exposed to criticism by the occupants and its owners.

This applies to dwellings, schools, hospitals, factories, churches, stores, offices, farm buildings, cold storage, etc.

If timber should rot, paint should peel, masonry crumble, ceilings and walls get discolored from water and dust streaks, there will also be criticism.

The author has tried to tell in simple language the important part that Radiation plays in these problems and the manner in which it does so, as well as the characteristics of Radiation. As far as possible the discussions have been limited to general problems and conditions that may be found in ordinary building construction.

***We will forward on request a free copy of the ORIGINAL complete work of the authority quoted, where an asterisk (*) appears in this booklet.**

COLD

"Does insulation keep out the cold?" is a question frequently asked.

The answer is: - only as do ordinary materials such as glass, brick, building paper, etc., to the limited extent that it prevents wind infiltration.

Cold is the absence of heat. It is heat that flows - in the direction of cold; except sometimes otherwise in convection, or in forced convection such as is produced by a fan.

Suppose windows were open, or there were holes or crevices in a heated building. Further suppose that the outside air, though very cold, were *absolutely* still. Cold would NOT come in. But HEAT would LEAVE, partly by convection, a little by conduction, and considerable by radiation, till thermal equilibrium between the building and the surroundings were reached.

Even without any openings or holes, even assuming the building were sealed *perfectly air-tight*, the heat would never-the-less leave that structure in winter, but with less rapidity; by radiation, conduction and convection.

Suppose two small, warm boxes, identical except that one had some openings in it, were placed into a very cold refrigerator with still air. Heat would leave both boxes until temperature equilibrium with the refrigerator was reached; but more rapidly in the case of the box with the openings.

So the problem is the study of the FLOW of HEAT, or "HEAT TRANSFER."

HEAT TRANSFER

All substances, including all building materials (and insulations), *transfer* heat or *resist* heat-flow by the same methods. The same laws of nature are obeyed by all physical objects, including aluminum, paper, cotton, wood, wood-fibers, rock, slag, glass, mineral wool, air spaces, plaster, brick, steel, humans, animals, plants, the sun, the earth, etc.

Heat flows only by Conduction, Convection and Radiation. The differences are in the INTENSITY of Conduction, the RATE of radiant Absorptivity and Emissivity) the AMOUNT of Convection.

These quantitative differences are due to differences in: density; weight; shape; permeability; molecular structure of surfaces; and other ordinary, physical properties.

DEFINITION OF TERMS

Btu or **B**ritish **T**hermal **U**nit. The amount of heat needed to raise the temperature of 1 lb. water 1 degree Fahrenheit. I 0F.

Conductivity or k factor, is the rate of heat flow in Btu's, per hour, through 1 sq. ft. of a *homogeneous material* that will result from a 1° F. temperature difference between its 2 surfaces, PER INCH OF THICKNESS. (Reflective insulation not being homogeneous, the *k* factor is *not applicable;* but the C, R, and U factors are applicable. As a matter of fact, *most* insulations are not homogeneous, since they contain a mixture of air spaces as well as fibers, and often also paper.) *k* is often confused with Conductance or C factor.

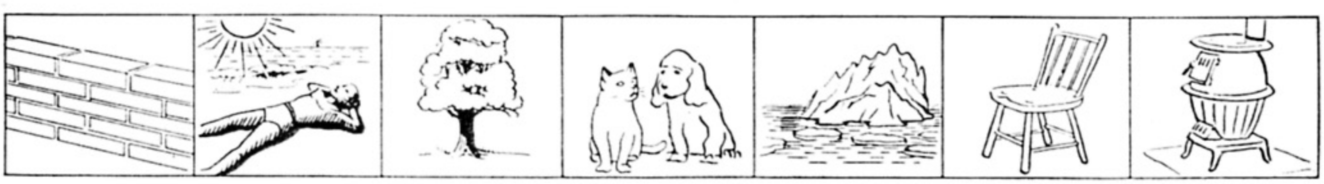
Conductance or **C factor** is the rate of heat flow in Btu's, per hour, through 1 sq. ft. of any material whether homogeneous or non-homogeneous, of whatever thickness or shape, resulting from 1° F. temp. difference between its 2 exteriors.

U factor is rate of heat flow, or "overall coefficient of heat transmission" in Btu's in one hour through one sq. ft. area of the entire depth of ceiling, roof, wall, or floor, including insulation if any, which will result from a 1° F. temperature difference between the air inside and the air outside.

R factor or **Resistance** to heat flow: - is the reciprocal of C, *k*,or U; in other words, mathematically $\frac{1}{C}$, $\frac{1}{k}$, $\frac{1}{U}$.

(The *smaller the C, k, or U factor* fraction, and the larger the R factor, the BETTER is an insulation.)

Conduction is direct heat flow *through* matter, resulting from actual *physical contact* of one part of the same object with its adjoining part, or from contact of one object with another. The object may be a gas such as air; or a dense solid such as iron, lead or uranium. The transmission of heat is by molecular motion, in which the molecules transmit their energy to adjoining molecules whose motion is thereby increased. This raises their temperature without significant displacement of the particles. The direction of heat flow by conduction is



THEY ALL OBEY THE SAME LAWS OF HEAT FLOW

from warm to cold only, in any direction; NEVER from cold to warm.

CONDUCTION

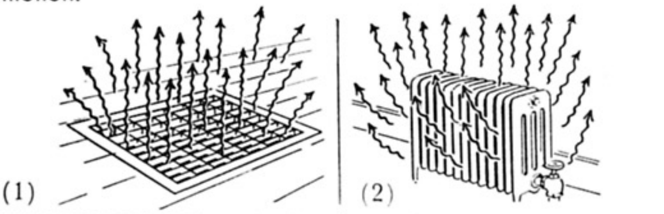
(1) *Through poker.*

(2) *Between top of closed stove and bottom of kettle.*

(3) *Film of air in immediate contact with surfaces of stove, kettle and poker.*

Convection heat flow is the transfer or transportation of heat which is within a gas or liquid, caused by the flow of the heated gas or liquid itself. In building spaces, convection heat flow is largely upward, somewhat sideways; not downwards.

Convection may be mechanical, such as by a fan; called "*forced* convection." It may be "*free* convection," by *natural* means, as usually occurs in building spaces. For instance when a *warmer* stove, convector, person, floor, wall, furniture, etc. first loses heat by Conduction to *cooler* air in contact with it, the added heat activates the molecules of the air. The warmed air expands and becomes less dense, and rises. Cooler, heavier air rushes in from the sides to replace it. The popular expression is, "*Hot air rises.*" Smoke rising from a chimney or cigarette, is also an example of convection. The motion is turbulently upward, with a component of sideways motion.



CONVECTION (I) Warm air rising from register. (2) Warm air rising from all surfaces of radiator (after air in contact with radiator has been heated by conduction).

AIR SPACES IN BUILDINGS

The greatest flow of heat possible between solids is by *direct conduction.*

Air-spaces in buildings, as in outer walls, roof and floor spaces, reduce heat flow by conduction, because air is a gas and has slight density. This reduces heat loss in winter, and heat intake in summer.

Because air has low density, **"The percentage of heat transferred by conduction through air is comparatively small."** (*Building Insulation*, page 104, P. D. Closet.)

A ceiling or roof *space* has a Resistance factor, R, against up heat flow of .76; against down heat flow as much as 1.06. A building wall *space* has a Resistance factor to the flow of heat sideways of .91. (The corresponding C factor values are C 1.32, C .94 and C 1.10 respectively.) If these spaces were eliminated, there would be that much *less resistance* to heat flow, and so greater heat flow, greater conductance.

However, an air space is a good medium for heat flow by radiation and convection, which create new problems.

The BUREAU OF STANDARDS in its Circular No.376 entitled "Thermal Insulation of Buildings" says on page 3,

"Although air is a very poor conductor of heat, the insulating value of an ordinary air space is rather small, on account of the large transfer of heat by convection and radiation. Radiation is largely responsible for the ineffectiveness of air spaces bounded by ordinary building materials, such as are found in frame or other hollow walls. The low insulating value is often erroneously attributed to convection; but, as a matter of fact, from 50 to 80 per cent of the heat transfer across air spaces of ordinary sizes takes place by radiation. If the air spaces were bounded by bright metallic surfaces, the transfer of heat by radiation would be greatly diminished, since clean metallic surfaces are much poorer radiators than non-metallic surfaces, such as brick, stone, glass, wood, paper, etc."

RADIATION

Thermal RADIATION is the transmission through SPACE of *energy* by means of electromagnetic rays of long wave length.

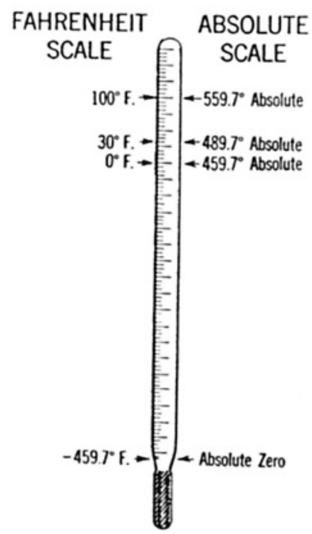
The sun, for example, radiates energy to the earth through 93 million miles of space, by means of rays of many different wave lengths. The rays which predominate are those of long wave length, called 'infra-red' rays, or heat-rays.

But the source does not have to be the sun, and the space does not have to be so large. Every exposed surface of every object in the universe with a temperature above *absolute zero* gives off infra-red rays in varying amounts. These rays travel through whatever space there may be between that surface and the surface of another object facing that space; be it an inch or a million miles away.

The *surfaces* of an iceberg, a wall, a stove, a radiator, a human being, clothing, animals, a chair, table, desk, floor, ceiling or roof, a piece of wood, paper, a dust particle, rock, ordinary insulation, etc., all radiate. All have some heat within them, all are above absolute zero in temperature. (Many problems of heat transfer are calculated and determined with the use of "absolute zero," instead of zero on the Fahrenheit or the Centigrade Scales.)

ABSOLUTE ZERO is the very lowest theoretical temperature that can be attained. It is minus 459.7° F., or 459.7 degrees below zero on the Fahrenheit scale. Therefore 459.7 is the amount to be *added* to the Fahrenheit temperature of an object in order to ascertain its *Absolute temperature*.

For example, a temperature reading of 30° on the Fahrenheit scale, would on the Absolute scale be 459.7° *plus 30°*, or 489.7°. A temperature of 100° F. would be 559.7° Absolute. *See illustration.*



THERMOMETER STARTING AT ABSOLUTE ZERO

Most rays are invisible! The few that are visible are known as *Light*. On either side of the light rays in the spectrum are the invisible ultra-violet and infra-red rays, which are now almost as familiar to the public as they are to scientists. The small range of visible rays : violet, blue, green, yellow, orange and visible red, all known as Light, constitutes only 1

‡*Mr. Close was Technical Secretary of Insulation Board Institute and previously Technical Secretary of the American Society of Heating and Air-Conditioning Engineers. Publishers: American Technical Society, Chicago, U.S.A. Price $4. 50.*

octave out of the 66 octaves of rays.

The different rays have different wave lengths, progressively longer on one side of the spectrum, and progressively shorter on the other side. The rays that lie between *one* ray of a certain length, and another ray which is twice as long or *half* as long, are called an octave. (A rough analogy is the more familiar octave in the field of music.)

The light rays have comparatively short wave lengths, and engender comparatively little heat. By far the greatest amount of heat is engendered by the series of rays called infra-red or heat rays, with their long wave-lengths, extending over many octaves.

Heat rays are not only invisible, but they have *no temperature; only energy.*

Heat rays are transmitted through space at great speed; about 186,000 miles per *second,* the same speed as that of Light. They travel till they strike another surface. Then they are either absorbed or reflected by that surface.

For example, the surfaces of the exposed portions of our bodies are constantly emitting heat rays to the surfaces around us, which in turn are constantly radiating to us.

DIRECTION

The direction of flow in radiation is said to be from *warm* to cold; because while there is a flow of rays from and to each surface facing the same space, only the *net* transfer of heat rays across a space between two surfaces is of practical importance. Infra-red heat rays travel away *from every point* of the surface in a straight line in any *direction,* with the greatest intensity perpendicular to the surface, decreasing to zero intensity *along* the surface. *Illustrated on page 21.*

"When a surface radiates heat, and every surface does unless its temperature is absolute zero, every point of the surface radiates heat in all directions." 1950 A.S.H.A.E. Guide, page 526.

THREE PROCESSES IN RADIATION

Radiation involves three processes. One is the flow of rays *emanating* from a surface of an object, because of heat within it. This is called Emission and its measure or rate is called Emissivity. The other two processes are called Absorption and Reflection; their rates, Absorptivity and Reflectivity.

BASEBALL AND SHOTGUN ANALOGIES

When a pitcher throws a ball, it is set in motion because of energy *within* the player. We might liken the movement of that ball to Emission or Emissivity from a surface.

When the ball is bunted and its direction reversed, we can liken that to Reflectivity of the ray by the 2nd surface.

The catching of a ball might be likened to Absorptivity by the receiving surface.

Picture a shotgun or machine-gun in action. The bullets emanating from the barrel because of energy from the powder charge, might be likened to the flow of rays which emanate FROM a surface, or Emissivity.

Now picture the same bullets striking a wall. Those which *penetrate are absorbed.* It might be likened to Absorptivity.

Those which do not penetrate might be said to be rejected, deflected. This might be likened to Reflectivity.

The percentage of bullets which penetrate and are absorbed, compared to those which do not and are reflected, depends to a large measure on the type of *surface* on the wall. A surface of cloth, wood, paper, etc. would result in a larger percentage of absorption (of bullets) and a smaller percentage of their reflection, than a surface of hard steel.

A third analogy: The flow of water from a hose might be likened to Emissivity; the absorption of the water by the surface sprayed, to Absorptivity; and the water which bounces back, Reflectivity.

EMISSIVITY

The RATE of heat-ray flow from a surface, or its emissivity, is related to the ability of that surface to absorb heat rays. It is measured by comparison with the rate of a surface which under the same conditions would absorb all the radiation which struck it and reflect none.

The *rate* of radiation from a surface is not affected by the distance apart of the two surfaces. They may be millions of miles apart, like the sun and the earth; or a few inches or feet apart, like the surfaces in building spaces.

The emissivity of a material is a physical property belonging to it, just as weight, color, shape, etc. are physical properties. It can he determined with good accuracy by standard measurement techniques. Emissivity describes the *rate* at which radiant heat energy is emitted by a given surface.

All materials have emissivities, theoretically ranging from *zero to one* (100%) in value. No energy at all would be radiated from a surface of zero emissivity, while at the other extreme is a surface with emissivity of *one* or (100%).

The term *"emissivity,"* which means the *rate* of heat ray flow from a surface, is *not* the same as the *amount* of heat ray flow. The amount will vary, with length of time of exposure, temperature, heat capacity of object, etc.

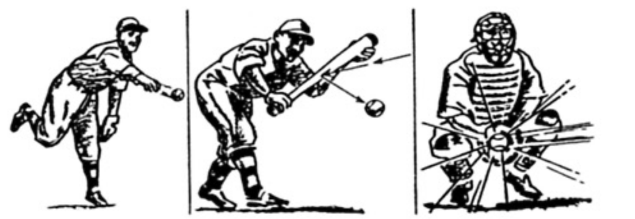
SURFACE DETERMINES EMISSIVITY

The emissivity of ordinary materials such as wood, paper, glass, rock, asphalt, slag, ordinary insulations, etc. is about 90% of the maximum rate. Commercially pure aluminum such as aluminum foil has an emissivity of only 3% to 5%; very close to the zero end of the emissivity scale.

If two objects alike in *every* respect including substance, size, weight, temperature, kind and area of surface; were both equidistant from and "faced" the same surface of a third object for the same length of time, not only the rate but the amount of heat-rays flowing from them to that other surface in a given time would be equal.

Regardless of the substance of which the two identical objects were composed, if the *surface* of one were then covered with a material of 90% emissivity, and the surface of the other with a material of 3% emissivity, there would result a drastic difference in the rate of radiation or heat-ray flow from these two otherwise identical objects.

For instance, take four identical, unpainted iron radiators of about 24% surface emissivity. Paint one with aluminum or bronze paint; another with ordinary paint. Cover the third with asbestos and the fourth with aluminum foil. Although all had the same temperature, the one covered with aluminum foil of 3% emissivity would radiate the least because it would have the lowest emissivity. The radiators covered with ordinary paint or asbestos would radiate most, because they have the highest emissivity, much higher than aluminum paint, even higher than the original iron. (See Table, page 22.) Painting *over* the aluminum paint or foil with ordinary paint, changes the *surface* to 90% emissivity.



EMISSIVITY REFLECTIVITY ABSORPTIVITY

ABSORPTIVITY AND REFLECTIVITY

When energy rays of any wave length strike the SURFACE of an object, *to the extent* that the rays are ABSORBED, *heat* is engendered in the object. This heat then spreads throughout the mass by CONDUCTION. The infra-red rays with their long wave lengths, engender *enormously* more heat than do light rays with their short wave lengths.

Heat-rays which are not absorbed by a surface which they strike, are TURNED BACK, reflected back.

The terms "absorptivity" and "reflectivity" *signify* rates at which heat-rays are absorbed or reflected by surfaces. There is a relationship between these rates.

Ordinary materials with high emissivity rates of 90% have a correspondingly high absorptivity *rate* of 90%. They also have low powers of reflection, 10%, for the long-wave-length heat-rays. But an aluminum foil surface with a very low emissivity rate of 3% has a correspondingly low absorptivity rate of 3%, and a high *reflectivity* of 97%.

In the case of a few materials, for instance gases (including air), a large portion of the heat rays can *pass right through* without being either absorbed or reflected. Pure rock salt, which is essentially sodium chloride, is also highly diathermic, and will permit a good deal of radiation to pass through without absorbing or reflecting it. Only a very small frequency range of the *heat* rays will be transmitted through quartz, glass and water; although these substances can transmit the rays of *light*, ARE *transparent* to light.

But the surfaces of most building materials including ordinary insulations, are high absorbers, high emitters, and poor reflectors of radiation, with an absorptivity and emissivity of about 90% and over, and a reflectivity of 10% or less.

Dr. J. L. Finek stated in the *Jan. 1935* issue of The Architectural Record,

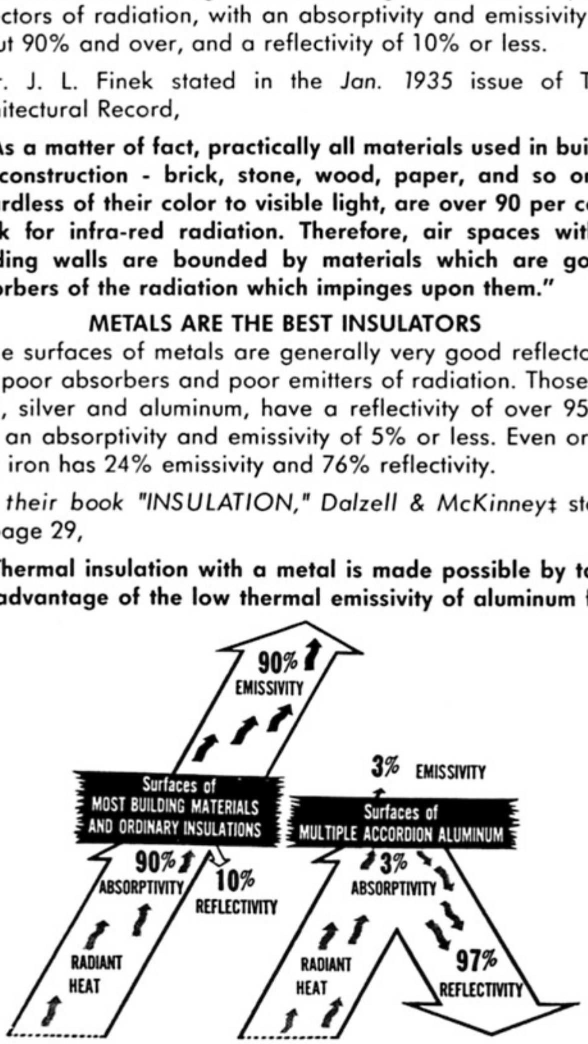
"As a matter of fact, practically all materials used in building construction - brick, stone, wood, paper, and so on - regardless of their color to visible light, are over 90 per cent black for infra-red radiation. Therefore, air spaces within building walls are bounded by materials which are good absorbers of the radiation which impinges upon them."

METALS ARE THE BEST INSULATORS

The surfaces of metals are generally very good reflectors, and poor absorbers and poor emitters of radiation. Those of gold, silver and aluminum, have a reflectivity of over 95%, with an absorptivity and emissivity of 5% or less. Even ordinary iron has 24% emissivity and 76% reflectivity.

In their book "INSULATION," Dalzell & McKinney‡ state on page 29,

"Thermal insulation with a metal is made possible by taking advantage of the low thermal emissivity of aluminum foil and the low thermal conductivity of air. It is possible with this type of insulation practically to eliminate heat transfer by radiation and convection."



SOLAR RADIATION

In summer, considerable radiation from the sun is absorbed by buildings, because the outer surfaces of most roofs and walls have high absorptivity.

Much of this radiant energy absorbed from the outside turns into heat, which flows by conduction through the solid material to the cooler inside surfaces of the roof and wall. The radiation inward from those inside surfaces, across building spaces, of invisible infra-red heat rays, is considerable, because these surfaces usually have over 90% emissivity.

Black non-metallic surfaces such as asphalt, slate, paint, paper, etc. are poor insulators against heat rays in either ease, outside or inside; with 85% to 98% absorptivity for solar radiation, and 90% to 98% in enclosed spaces.

Aluminum paint or gilt paint, while it lasts, has a radiant heat absorption and emissivity of 40% to 60% in *enclosed spaces*. It performs better outdoors, with only 30% to 50% absorption for direct solar radiation. 1955 ASHAE GUIDE, p. 95.

White paint, whitewash, white tile, white brick and plaster perform well *outdoors*, with an absorptivity for solar radiation of only 30% to 50%. But they perform very poorly in *enclosed spaces*, no better than black paint, with an absorptivity and emissivity of 85% to 95%. 1955 ASHAE GUIDE, p.95.

Brick of any color, and concrete, in enclosed spaces, have an absorptivity and emissivity of 85% to 95%. But for solar radiation outdoors, red brick and concrete have an absorptivity of 65% to 80%; while yellow and buff brick have 50% to 70% absorptivity.

One reason for this difference between indoor and outdoor absorptivity and emissivity is that in addition to the infra-red heat-rays of frequencies or wave lengths corresponding to those found at ordinary building air space temperatures; the sun emits heat rays of frequencies or wave lengths corresponding to a broad range of *other* temperatures. The sun also emits other rays, visible and invisible. All these rays, with heat-rays predominating, engender a certain amount of heat when they strike a surface and are absorbed, for example by the outer surface of the roof or wall of a building.

There is also sky or diffuse radiation from the surrounding atmosphere, also from buildings, trees, etc.

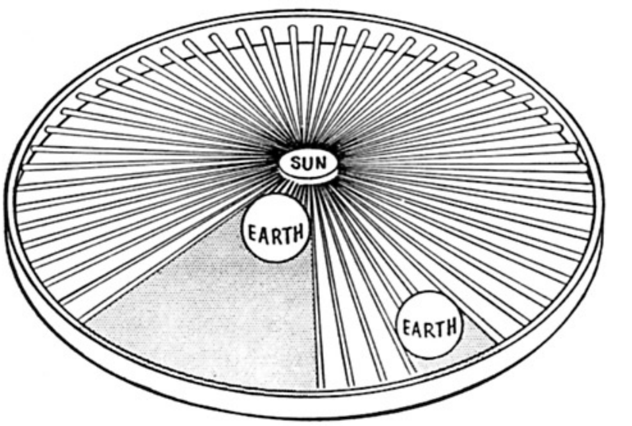
Enclosed building spaces are usually without light. Everything is dark and colorless. Radiation between surfaces in such space is limited largely to invisible, infra-red heat-rays.

MATHEMATICS IN RADIATION

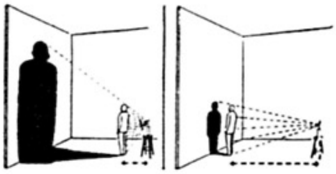
It is our good fortune that there are two natural factors which intrude on the processes of radiation from the sun to the earth, and the absorptivity of its infra-red heat rays. They prevent us from being consumed by the sun's burning energy waves. One factor is the absorption of about a third of the rays which would otherwise reach us, by the atmosphere surrounding the earth.

The other is the operation of the well-known **Inverse Square Law** which describes mathematically how the intensity of radiation is lessened in traveling through space. This stems from the fact that *every point* of a surface radiates in *every direction*. It is not that the strength of the *individual* ray is lessened by distance; but that the *number* of rays which are *intercepted* is less. Each ray travels with undiminished energy, regardless of distance, short or great.

‡*J. Ralph Dalzell, B.B., Head Architectural and Engineering Dept., and James McKinney, Educational Director of American School, Publishers, American Technical Society, Chicago, U.S.A.*

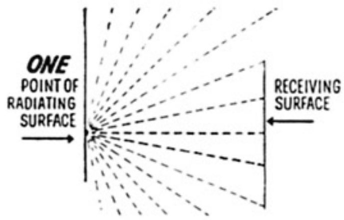


Imagine that a *point of a surface* is the sun, and picture the sun as the hub of a wheel, with the heat rays as the spokes *(see illustration)*. Then it can he seen that the closer to the sun (hub, point) a body is, the more rays (spokes) it will intercept. If the Earth were closer to the sun, say as close as the planet Mercury, it would receive many more rays than it does now. The intensity of radiation would be so great that life as we know it could not survive.



An analogy with *light* rays instead of *heat* rays might be more familiar and also illustrative. We have all seen the difference in the amount of light rays which a body intercepts when it is close to the source of light, and the smaller amount when the same body is further distant from the same source of light.

Since *every* point of a surface emits invisible infra-red heat rays, which travel away from that point in a straight line in any direction, but with the greatest intensity perpendicular to the surface, decreasing to zero intensity parallel with the surface; one might illustrate emission from *one* point (of all the countless points of a surface) as herewith.



The intensity (or energy per second per unit area) of the flow of infra-red heat rays from a point source on a surface which is emitting radiation, to a receiving surface, varies *inversely* as the square of the distance between the source of radiation and the surface which absorbs the rays.

Precisely, the law states that the intensity of radiation on a receiving surface is in proportion to the inverse of the square of the distance from the source, or mathematically,

$$I = B/r^2$$

$$\text{where} \begin{cases} I = \text{the intensity of radiation} \\ r = \text{the distance between the bodies} \\ B = \text{a constant of proportionality} \end{cases}$$

But when discussing radiation in this booklet, we need not dwell upon great distances such as the millions of miles from the sun to the earth. For *every surface of every object* exposed to space is *continually radiating*, emitting heat rays *each* of which travels with undiminished energy until it reaches another surface whether it is near or far away. The ray is then generally either absorbed or reflected (in a very few cases transmitted).

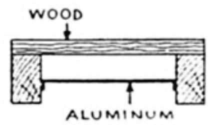
The Inverse Square Law plays a negligible part in radiant heat transfer across building spaces, because the radiating and receiving surfaces are parallel and in close proximity. Therefore essentially all the rays emitted from one of the surfaces in such space reach the facing surface; unless some material is introduced into the space to interfere.

The transmission of heat by radiation varies as the difference of the fourth powers of the *absolute temperatures* of the radiating and receiving bodies. ("Absolute temperature" is 459.7° plus Fahrenheit temperature.)

Referring back to the absorption of some of the sun's rays by the Earth's atmosphere, which saves us from being burned up by them; this absorption by the atmosphere also saves many of us who live in the cooler regions, and probably all of us, from being frozen to death at night. Although in connection with heat flow by Conduction through building spaces, the low density of air has special significance; actually the atmosphere of dust particles, vapor and gases surrounding the Earth absorbs sufficient heat rays from the sun to keep us tolerably warm, even during the time the sun is not shining on us and on the atmosphere around us.

SUN'S RAYS HAVE NO TEMPERATURE

The sun's rays themselves have no temperature while traveling only through space. Their absorption by the surface of the Earth would create warmth *only in the Earth*. It is the absorption of the energy rays by the surfaces of the *dust particles in the air* and their conversion into heat, which helps keep the atmosphere we live in bearably warm. This radiation to the dust particles flows principally from the sun. But there is also some radiation from the earth to these particles, and in the warmer regions, from the earth to the people. There is even conduction in the warmer regions to people's feet. But in the cooler regions, or during cold weather anywhere, or in a cold-storage plant, etc., there is loss of heat by people not only by radiation *to* Earth, but also by conduction *from* the warmer feet to the colder earth. *See* CRAWL SPACE *illustration, page 28.*



That is one reason why floors should be insulated in the colder regions. Where this has not been done, a good and inexpensive make-shift in factories, offices, etc., is a wooden platform 1" or 2" in height, with a sheet of aluminum in the center of the space.

Occupants can stand on this platform while at work, or place their feet on it while sitting. It is effective against heat flow by conduction, because air spaces are very poor conductors, and even the wood is not a good conductor. But it is effective against heat loss by *radiation*, also; because the spaced aluminum sheet is effective in reflecting back most of the heat rays which reach it.

MEAN TEMPERATURE, TEMPERATURE DIFFERENCE

In addition to emissivity, the *temperature* DIFFERENCE between the two surfaces which bound an air space, plays an important part in heat flow by radiation. So does increase or decrease in mean temperature, but not in the case of reflective insulations.

An increase in temperature of a surface results in emission of more rays from each and every point of that surface, with many of the rays having a higher frequency and greater energy than those emitted at the lower temperature.

ASHAE 1954 GUIDE, page 178: **"The radiation portion of the coefficient is affected by the difference in temperature between the boundary surfaces and by their respective emissivities and is practically independent of depth."**

MEAN TEMPERATURE AND TEMPERATURE DIFFERENCE are terms often used in connection with air spaces and insulation. To illustrate, if a space has a temperature of 70° F. on one side, and on the other side 10°F., it has an average or *mean temperature* of 40°F. It has a temperature *difference* of 60°F. between the 2 sides or surfaces.

Profs. Wilkes, Heebler, and Queer, of M.I.T. and Penn State College state on page 120 of their booklet "Thermal Test Coefficients of Aluminum Insulation for Building",* published by the American Society of Heating and Air Conditioning Engineers,

"For most insulating materials the conductance increases with mean temperature. That this is not the case for reflective insulation is shown in Fig. 7..."

The greater the temperature difference between two s faces, the greater the difference in the net flow from warmer surface to the colder surface, particularly since variation is with the difference of the *fourth* powers of th absolute temperatures.

However, the less the temperature difference, the mo marked the *decrease* in net flow. This explains why *para* sheets of reflective surfaces creating *multiple reflect spaces* result in increasing insulation values for each spa for what might be termed a law of increasing returns. S*page 30 under heading, A Law of Appreciating Returns*

The transmission of heat by *Radiation* across a spa

RADIATION TABLE

Emissivity, Absorptivity and Reflectivity of Surfaces

SURFACES at 70°-100° F		Emissivity and Absorptivity	Reflectivity	Authority
ALUMINUM	Foil	.02 to .05	.95 to .98	Critical Table
	Polished	.02 to .045	.955 to .98	Natl. Bureau of Standards
	Al. Paint	.40 to .65	.35 to .60	E. Schmidt
ASBESTOS	Board.	96	.04	E. Schmidt
	Paper	.93	.07	E. Schmidt
ASPHALT		.90 to .98	.02 to .10	ASHAE Guide
BRASS	Natural Surface	.06 to .07	.93 to .94	E. Schmidt
	Polished	.05	.95	E. Schmidt
BRICK		.93	.07	E. Schmidt
CHROMIUM	Polished	.08	.92	Natl. Bureau of Standards
CONCRETE		.85 to .95	.05 to .15	ASHAE Guide
COPPER	Polished	.04	.96	Natl. Bureau of Standards
	Oxidized black	.78	.22	E. Schmidt
ENAMEL, white		.92	.08	E. Schmidt
GLASS, polished		.95	.05	E. Schmidt
GOLD		.02	.98	Natl. Bureau of Standards
ICE		.96	.04	E. Schmidt
IRON		.242	.758	E. Schmidt
	Polished	.06	.94	Natl. Bureau of Standards
	Rusty	.85	.15	Natl. Bureau of Standards
MARBLE, polished		.931	.069	E. Schmidt
MONEL metal, polished		.02 to .05	.95 to .98	ASHAE Guide
NICKEL		.11	.89	E. Schmidt
	Polished	.06	.94	E. Schmidt
OIL, on polished metal				
	Very thin	.06	.94	E. Schmidt
	.001" thick	.27	.73	E. Schmidt
	.002" thick	.46	.54	E. Schmidt
	.005" thick	.72	.28	E. Schmidt
PAINT, Ordinary, including White		.85 to .95	.05 to .15	ASHAE Guide
	Aluminum, Gilt or Bronze	.40 to .60	.40 to .60	ASHAE Guide
	Whitewash	.85 to .95	.05 to .15	ASHAE Guide
	Varnish	.89	.11	E. Schmidt
PAPER	White	.94	.06	E. Schmidt
	Roofing Paper	.91	.09	E. Schmidt
PLASTER		.93	.07	E. Schmidt
PORCELAIN		.94	.06	E. Schmidt
SILVER, polished		.01	.99	Natl. Bureau of Standards
SLATE		.90 to .98	.02 to .10	ASHAE Guide
STEEL,	Polished	.07	.93	Natl. Bureau of Standards
	Rusty	.80	.20	E. Schmidt
	Sheet, polished	.20	.80	Am. Soc. Refrig. Engineers
TILE, white		.85 to .95	.05 to .15	ASHAE Guide
WATER		.96	.04	E. Schmidt
WOOD		.90 to .92	.08 to .10	E. Schmidt

bounded by two surfaces increases as the mean temperature of the space increases, even though temperature difference between the two surfaces remains the same. That is because the hotter a surface becomes, the more heat rays it will give off per unit of time and this is out of proportion to the increase in temperature.

According to the **Stephan-Boilzmann Law** applied to the ideal case of a black body" (a perfect radiator or absorber), heat rays will be emitted at an intensity in proportion to the 4th power of the temperature, or

$$I = AT^4$$

$$\text{where} \begin{cases} I = \text{Intensity of Radiation} \\ A = \text{Constant} \\ T = \text{Absolute Temperature} \end{cases}$$

In Housing and Home Finance Agency Research Paper 32*, prepared by the National Bureau of Standards, the value for hr is presented to partially describe a coefficient for heat transfer by radiation across a plane air space, as follows:

$$h_r = \frac{0.172 \times 10^{-8}(T_1^4 - T_2^4)}{(T_1 - T^4)}$$

where T_1 and T_2 are the absolute temperatures of the bounding surfaces, and (0.172×10^{-8}) is a constant value.

Let us, for an example, assume that two wall surfaces facing each other across a building air space are at 0° F. and 200° F. and that they are subsequently raised to 100° F. and 120° F. respectively. Substituting the *absolute* temperatures in the above formula in the two cases, we find

$$(1) \quad h_r = \frac{0.172 \times 10^{-8}(480^4 - 460^4)}{(480 - 460)} = 0.713$$

$$(2) \quad h_r = \frac{0.172 \times 10^{-8}(580^4 - 560^4)}{(580 - 560)} = 1.270$$

Notice that though the temperature difference is the same in both cases, the result is a good deal larger in the second case where mean temperature was 100° F. higher.

To finally determine the radiation coefficient, or the heat actually transferred across an air space by radiation in Btu, per hour, per square foot, per degree F., the above result is multiplied by a factor 'E' called by the National Bureau of Standards 'effective emissivity of the space."

The value of 'E' is about .85 for spaces where both bounding surfaces are ordinary material. E is about .05 for spaces having one of the bounding surfaces of a low emissivity material such as aluminum. This means that the very large amount of heat transferred across an ordinary air space by radiation, *is reduced by about 94%* when *one* of its surfaces is made highly *reflective* to infra-red heat radiation.

Further, it can be seen that the previously mentioned effect of variation in air space efficiency with mean temperature becomes reduced to *relative insignificance upon making one surface reflective.* The radiation coefficients or heat flow by radiation for the two cases shown above with one surface reflective, are

(1) $E\,h_r = (.05)\ (0.713) = .0357$ Btu.

(2) $E\,h_r = (.05)\ (1.270) = .0635$ Btu.

The difference in this case for *100° F. change in mean temperature*, is only .0635 Btu less .0357 Btu, or 0.028 Btu, or about 3 one-hundredths of 1 Btu.

The 1954 Heating and Ventilating Guide, page 169, contains a chart which shows a *"Typical variation of thermal conductivity with mean temperature"* for ordinary insulations.

Profs. Allcut and Ewens of the University of Toronto School of Engineering Research made many tests of such variations. The following four, taken from page 37 of their booklet, *"Heat Insulation as Applied to Buildings and Structures,"* show a variation up to 50% with varying mean temperatures and temperature differences.

"The Air Force crash entry suit consists of multiple layers of metallic foils and high-temperature-resisting conductive insulation, and is designed to provide adequate protection up to an exterior temperature of 2000°F."

From a letter by
COL. E. J. KENDRICKS, Medical Corps (USAF), Chief, Aero-Medical Laboratory, Engineering Division

U. S. AIR FORCE CRASH FIRE FIGHTERS DEMONSTRATE:

Radiation DOMINATES HEAT FLOW IN AIR SPACES, AND METAL SURFACES HAVE LOW ABSORPTIVITY OF HEAT RAYS

Infra-red heat rays travel through space, including icy-cold air, in every direction, up, down, sideways, from warm to cold. They engender no heat until absorbed by a surface.

A news release from Wright Patterson Air Force base says of the accompanying photograph:

"In the center the 'bunkin' suit, now in use by airplane crash fire-fighters, has become too hot for its wearer and is being wet down. The aluminum foil laminate suit at the left, developed by AMC's Aero-Medical Laboratory, was found to give its wearer the greatest comfort and protection and suffered least damage during the test. The foil reflects the extreme heat and helps the wearer retain a relatively low body temperature while fighting airplane crash fires."

Specimens packed in wooden box with plywood sides.

Mean temperature, °F	59.74	71.21	74.63	87.08
Temperature difference, °F	29.00	44.38	60.21	76.72
Conductance "C"	.0994	.1137	.1320	.1482
Conductivity "k"	.397	.455	.528	.593"

In his 1949 booklet, *"Thermal Conductivity Tests and Results,"* Prof. Allcut on page 13 states, **"The fundamental characteristic of most insulating materials is that they contain pockets of air, and depend mostly upon these air pockets for their insulating value. Thus it can be expected that the variations in their thermal conductivities will be closely related to the corresponding variation in air, although they will also be influenced by the nature and the macroscopic structure of the material itself. This conclusion is supported by the fact that virtually all insulating materials have increasing conductivities with increase in mean temperature, the same type of change as that shown by air."**

REFLECTION CAN OCCUR ONLY IN SPACE

Reflection and Emissivity by surfaces can occur ONLY in SPACE. (Without space *between* surfaces, there would be direct contact *between* solids, and heat flow would be by *conduction only*.)

When a reflective surface of a material touches a ceiling, floor or wall, *that particular reflective surface* ceases to have radiant insulation value at the points in contact.

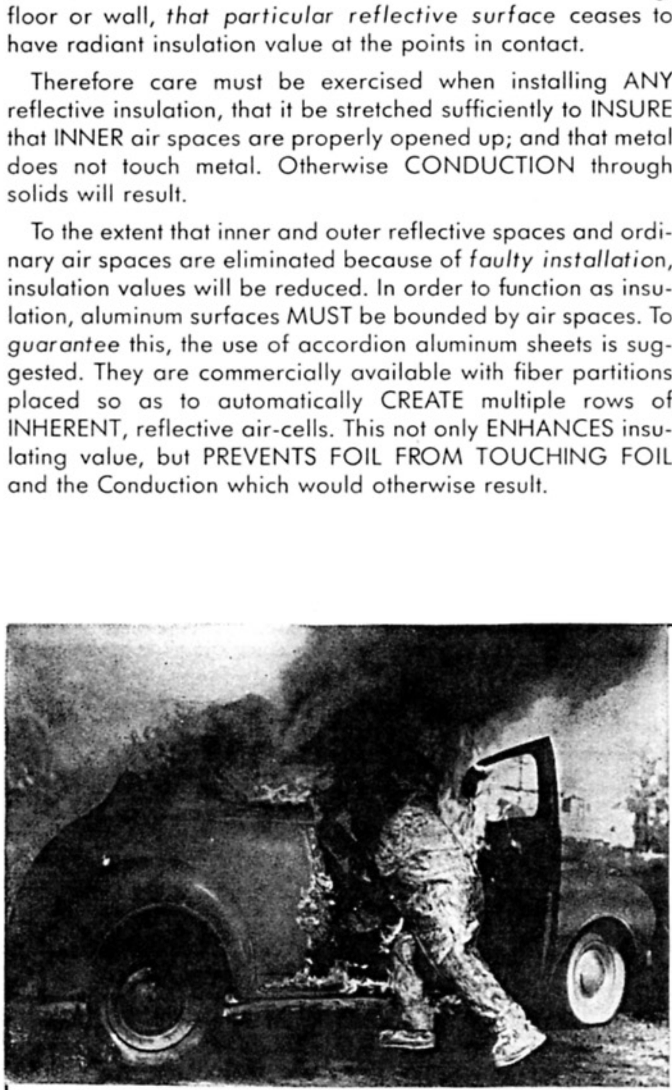
Therefore care must be exercised when installing ANY reflective insulation, that it be stretched sufficiently to INSURE that INNER air spaces are properly opened up; and that metal does not touch metal. Otherwise CONDUCTION through solids will result.

To the extent that inner and outer reflective spaces and ordinary air spaces are eliminated because of *faulty installation*, insulation values will be reduced. In order to function as insulation, aluminum surfaces MUST be bounded by air spaces. To *guarantee* this, the use of accordion aluminum sheets is suggested. They are commercially available with fiber partitions placed so as to automatically CREATE multiple rows of INHERENT, reflective air-cells. This not only ENHANCES insulating value, but PREVENTS FOIL FROM TOUCHING FOIL and the Conduction which would otherwise result.

Try this experiment. Write us for a free sample of multiple accordion aluminum insulation. Hold it close to your cheek, without touching. Usually the metal is cold enough so that the predominant flow of infra-red rays is from the surface of your face to the surface of the metal. Yet instead of feeling cool, your cheek will soon feel warm. *The explanation:* the Emissivity or rate of heat radiation of the surface of your face, like that of the surfaces of ordinary materials, is over 90%. The Absorptivity of multiple accordion aluminum surfaces is only 3%. It reflects back the rays at a 97% rate. The speed at which the rays travel both in radiation and reflection from and to your face is 186,000 miles per second. The Absorptivity of your face, like that of surfaces of ordinary materials, is over 90%. When these reflected rays are absorbed by your face, their energy is converted to heat.

The very same thing occurs when fuel heat tries to escape in winter FROM a house insulated with multiple accordion aluminum and also when heat tries to ENTER in summer.

Another experiment. Place a piece of multiple accordion aluminum above a heat bulb or a warm surface, as shown in this booklet on page 48. Place your fingers INSIDE, above the bottom aluminum sheet and *between* it and the fiber. Feel first the warm aluminum surface *below*. Then feel the cooler fiber directly above. Even when warm, aluminum radiates at a *low* rate, has a low emissivity.



DEMONSTRATOR is unconcerned by roaring flames as he rescues dummy from behind wheel of auto. Flexible material is as light as ordinary suit and coat.

FIRE FIGHTING SUIT WITHSTANDS TEMPERATURES OF 2,500° F.

Sunday's N.Y. News, Feb. 6, 1955, showed the new Fire Fighting Suit in action. It was reported to withstand temperatures up to 2,500° F. The suit was made with flame-resistant fabrics and metallic layers covered with aluminum.

They said the new suit "works on the principle of heat reflection. Because of its aluminum foil surface, 95% of the heat bounces off. What's equally important, temperatures inside the suit remain normal..."

REFLECTIVE SPACES

A space which is bounded by at least one surface which is highly reflective to heat rays, is called a reflective space.

SURFACE NOT FACING HEAT ALSO EFFECTIVE

In Close's book, *"Building Insulation,"* page 102, we find,

"As far as the rate of heat transfer across an air space is concerned, it makes NO DIFFERENCE whether the reflective surface is on the COOLER or warmer side of the space."

One sheet of aluminum in the CENTER of an air space creates 2 reflective air spaces and thereby has TWO efficient reflective surfaces at the *same time*, regardless of the direction of heat flow. The surface which faces the flow of heat absorbs radiation at a rate of but 3%, reflecting it back at a 97% rate. *Simultaneously* and *independently*, its *other* surface *emits* heat rays at only a 3% rate.

Each full reflective *space*, in upward heat flow, is equivalent to about 2/3" of ordinary insulation. For upward heat flow, the two surfaces of ONE sheet of aluminum together with the TWO reflective spaces which they face, have a combined efficiency equivalent to more than 1" of ordinary insulation. To obtain still better results, *additional* reflective air spaces must be added.

For example, suspending in space 5 sheets of aluminum 1" apart; or 3 sheets of aluminum separated by 2 sheets of fiber, all spaced 1" apart; creates *six* reflective *spaces*, the thermal equivalent of over 4" of ordinary insulation for upward heat flow and more than 9" for downward heat flow.

1 SURFACE IN 1 SPACE

Another important phenomenon is that a second aluminum surface bounding the SAME air space has little insulation value. ONE aluminum surface in a space has about 3% emissivity or 97% reflectivity against radiation, leaving but a small potential for a second such surface in that space.

Bulletin No. 19, Technical Notes No. 43 of the *National Housing Agency*, based on information furnished by the National Bureau of Standards, states on page 2:

"When any air space is faced with two reflective surfaces the resistance will be equal to those shown for one reflective surface plus 5%."

That is the reason why, with very little reduction in insulation value, 6 reflective spaces are being prefabricated *economically* into multiple accordion insulation, with only 3 sheets of aluminum (instead of 5), plus 2 sheets of *less expensive* fiber. EACH of the SIX aluminum surfaces of the 3 sheets has 97% reflectivity and only 3% emissivity, and there is but ONE such aluminum surface in *each* air space.

50% TO 93% HEAT FLOW BY RADIATION

Depending on direction of heat flow (because of the varying role Convection plays in the transfer of heat across building spaces), Radiation is responsible for 50% to 93% of all such heat flow.

WALL AND ROOF SPACE HEAT FLOW

Walls and roofs are built with air spaces. This minimizes heat flow by Conduction thru solids. Conduction is only about 5% to 7% of all heat flow in any direction through such air space, because air has slight density. Convection currents account for about 15% to 28% of such heat flow across wall spaces, up to 45% for up-heat flow in ceiling and roof spaces, and practically zero for down-heat flow.

THE AUTHORITIES SAY

All authorities agree that 65% to 80% of the heat that passes across the space from the warm wall to the colder wall, summer and winter, is radiant heat. So an important problem is to decrease radiant heat flow (and to a less extent also convection) across this air space.

Paul D. Close says on page 106 of "Building Insulation" that "such radiant heat transfer may vary up to 70 percent or more in the case of air spaces."

Prof. E. R. Queer, of Penn. State College, in a paper entitled *"Importance of Radiation and Heat Transfer Through Air Spaces;"** published by the American Society of Heating and Air Conditioning Engineers, states: **"Heat is transmitted across confined air spaces by radiation, convection and conduction."**

"It has been generally supposed that most of the heat lost through air spaces of building structures was by conduction and convection. However, this is not the case; most of the heat transferred between conventional building materials is by radiation."

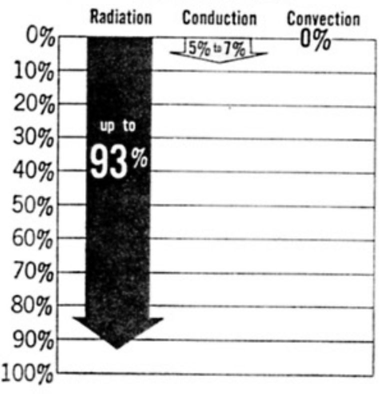
Dr. J. L. Finck, director of the Finck Laboratories, Brooklyn, New York, formerly with the U.S. Bureau of Standards, stated in the Jan. 1935 issue of *The Architectural Record*:

"It is an experimental fact that, of the total heat transferred across an air space, from 50 to 80 percent is transferred by radiation."

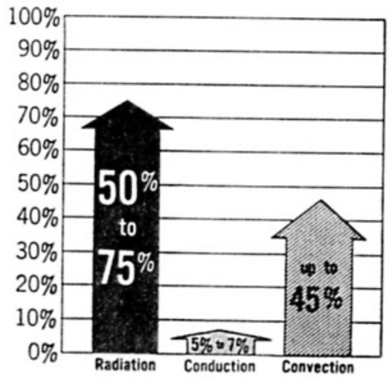
PERCENTAGE OF HEAT FLOW ACROSS BUILDING SPACES

BY RADIATION, CONDUCTION & CONVECTION

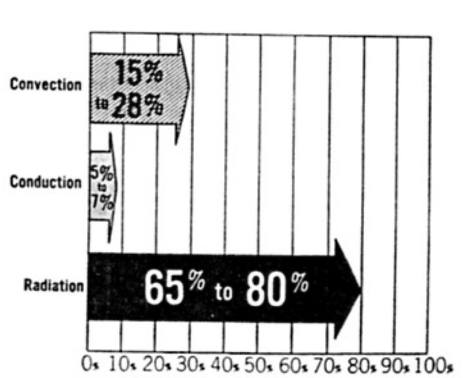
DOWN HEAT FLOW



UP HEAT FLOW



SIDE HEAT FLOW



MODIFYING AND CONTROLLING HEAT FLOWING BY
RADIATION, CONVECTION AND CONDUCTION

L. W. Schad, research engineer(of Westinghouse Electric Co., gives estimates for radiant heat flow across *wall* spaces which are most conservative, namely 65%; while other authorities vary up to 80%. (This might he partly accounted for by the fact that in Mr. Schad's tests, the temperatures of the hot and cold surfaces were 2120 and 320 F., or a difference of 1800 F.; whereas in many other tests and in actual building situations, the temperature difference does not often exceed 700 F.) The following quotation is from his booklet *"Insulating Effect of Successive Air Spaces Bounded by Bright Metallic Surfaces,"** published by the American Society of Heating and Air Conditioning Engineers. (Note high temperatures used)

"The value of air spaces as thermal insulation is often discussed without reference to the character of enclosing walls. The character of bounding surfaces greatly affects the amount of energy transferred by radiation which is the only way of modifying the total heat transferred across a given air space. The importance of radiation is often overlooked, especially in problems involving ordinary room temperatures...."

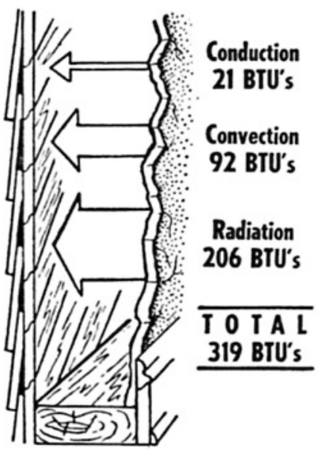
The following examples will illustrate the use of these equations and at the same time show how much the transfer across a given air space may be modified. The distance between the hot and cold walls is $1\frac{1}{2}$ in. and the temperatures of the hot and cold surfaces are 212° and 320° F., respectively. In Case I the enclosing walls are paper, wood, asbestos or other similar material having a radiation constant of approximately 0.9, while in Case 2 the walls are bright metal with a radiation coefficient of 0.15. In Case 3 two bright metal screens are used thus dividing the enclosure into three 1/2 in. spaces.

"BTU TRANSFERRED PER HOUR PER SQUARE FOOT BY CONDUCTION, CONVECTION AND RADIATION

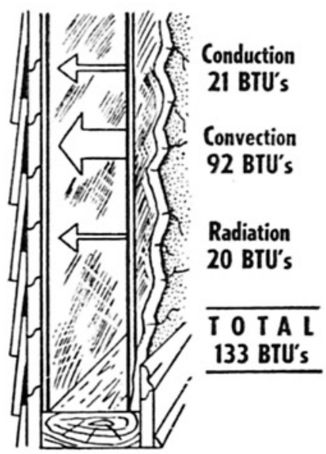
	Case I	Case 2	Case 3
Conduction	21	21	23
Convection	92	92	23
Radiation	206	20	7
Total	319	133	53"

SOME WALL SPACE HEAT FLOW TESTS

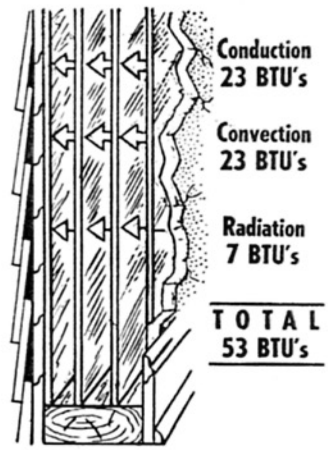
Based on above figures from ASHAE booklet, *"Insulating Effect of Successive Air Space Bounded by Bright Metallic Surfaces."



CASE 1
Uninsulated wall space



CASE 2
Inner surfaces lined with 15% emissive metal



CASE 3
2 sheets of 15% emissive metal make 3 reflective spaces

CASE 1: – Uninsulated wall space. The surfaces of ordinary building materials have an emissivity of more than 90%, and a heat ray absorption rate of over 90%. Air has low density, so Conduction through wall space is slight, only 21 BTU's. There is nothing to block convection, by which are transferred 92 BTU's. **Note: 206 BTU's out of total 319 BTU's going across this wall space was Radiation, or 65% of the total flow of heat.**

CASE 2: – The same wall space except that inner surfaces were lined with sheets of metal of 15% emissivity and absorptivity. *(Aluminum foil has only about 3% emissivity and absorptivity.)* Note drastic drop in heat flow by Radiation, from 206 BTU's to 20 BTU's. Conduction (the same air space), remains the same. With nothing to retard or block its passage, Convection remains the same. (Conduction and Convection are not affected by emissivity.) **Original total of 319 BTU's dropped to 133 BTU's.**

CASE 3: – Two sheets of 15% emissive metal divide the wall space into 3 reflective spaces. *(prefabricated multiple aluminum insulation is available with 4 and 6 reflective spaces.)* Heat loss by Radiation dropped to 7 BTU's against original 206 BTU's, or 94%. The 2 sheets block Convection so that its flow fell from 92 BTU's to 23 BTU's, or 75%. Conduction rose insignificantly, only 2 BTU's; from 21 to 23 BTU's, despite the presence of all that metal, because they were separated by low density, low conductive air spaces **The total flow in BTU's dropped 85%, from the original 319 to 53 BTU's.**

DOWN HEAT FLOW

Because of the absence of Convection, there is considerable difference in the Conductance even of an ordinary air space for down heatflow, as compared to up and side flow.

Horizontal air spaces of 3/8" depth, having boundary surfaces of .83 emissivity, were reported by Profs. Wilkes and Peterson in the 1954 ASHAE Guide, Page 178, to have values for upward heat flow of C I r32 ; vertical spaces (wall, sideways) a value raf C 1.17; and horizontal spaces with heat flow downward, a value of C .94.

The reduction in heat flow through space, where at least one bounding surface is as low emissivity and high reflectivity, has already been shown to be considerable with upward and sideward heat flow, as compared to a space with highly emissive bounding surfaces. But the reduction for downward heat flow is even more drastic.

WHY? Because there is no Convection downwards. Heated air, being lighter, rises when displaced by colder, heavier air. Since Conduction flow through air is slight, in downward heat flow there is essentially only radiation to contend with, and aluminum surfaces reflect it back at a 97% rate.

In Vol. 31, page 824 of Industrial and Engineering Chemistry, Dr. I. Li Flinck states:

"Let us now consider the heat transfer between two plane parallel surfaces. If the surfaces are horizontal, with the hot surface over the cold surface, there will be no convection, only conduction and radiation. In all other positions we will have all three modes of heat transfer."

Prof. G. B. Wilkes of the Mass. Institute of Technology, and Prof. E. R. Queer of Penn. State College Experiment Station, state in their booklet, *"Thermal Test Co-efficients of Aluminum Insulation,"** published by the American Society of Heating & Air Conditioning Engineers:

"For reflective insulation orientation must be considered. An unusually low heat-transfer value is obtained with the heat flowing down. This is particularly striking in the horizontal positions. . . . In these cases the major portion of the heat transfer is by conduction while radiation and convection are a minimum..."

Progressive Architecture, Nov. 1949, page 76, states,

"The heat storage capacity of reflective insulation is low. As a result, it does not store heat during summer days, only to pass it on down into the rooms of the house from the attic at night when coolness is most apt to be desired from the point of view of sleeping comfort."

"The conclusion from these various facts is that, at least as far as present knowledge goes, reflective insulation is one of the essentials far a weather-conditioned house in a region that has hot summers."

Prof. Gordon B. Wilkes in an article "Reflective Insulation" appearing in Industrial and Engineering Chemistry, Vol. 31, No. 7, Page 832, states, **"The heat capacity of aluminum foil, as installed, is about one-fortieth that of an insulating material weighing 8 pounds per cubic foot."**

On Page 833 of the same article Prof. Wilkes states: - **"The heat transfer through ordinary insulating materials is primarily by conduction, whereas the heat transfer across an air space with reflective surfaces and an 0.75 inch in thickness is primarily by convection."**

But there is no convection *down*, only up and sideways.

SUMMER COMFORT

The National Bureau of Standards, in its booklet BMS 52* "Effect of Ceiling Insulation Upon Summer Comfort," lists on page 10 *"the insulations tested"* in the *"order of decreasing effectiveness in protecting the ceiling against summer heat"* as follows:

1. Two layers of aluminum foil (both sides of each layer reflecting).

2.Full-thick ($3\frac{5}{8}$ inches) ordinary insulation.

3. One layer of aluminum foil (both sides reflecting).

For cooling and air-conditioning, some engineers recommend 6" of ordinary insulation in ceilings with 3" in walls, or the equivalent in aluminum and reflective spaces.

The chart, page 31, shows that both 6" and 3" equivalents can be achieved for down and wall heat flow respectively, with 2 sheets of aluminum forming three 1" parallel spaces.

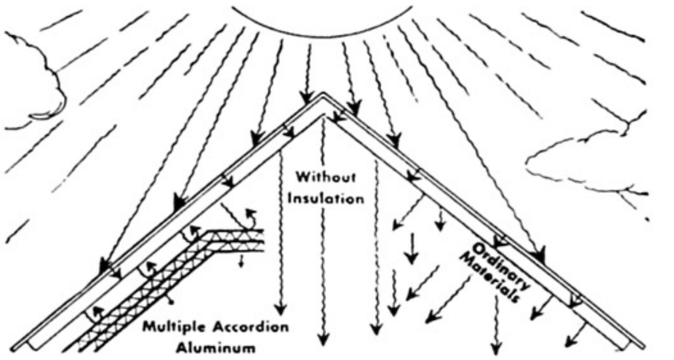
According to a well known authority, the summer heat load on a roof can be reduced from a potential of 19,000 Btu per hour to as little as 600 Btu by proper detailing of a house, including the use of multiple aluminum insulation.

This shield against radiant heat lifts part of the load from house-cooling equipment, reducing installation and up-keep

An Empty Roof Space Would Be The Best Insulation Against Summer Sun *Were It Not For Radiation*

To be comfortable in summer you must ward off unwanted heat rays or radiation. Most heat flow through a roof space in summer is by radiation. There is no convection down, and little conduction through low density air. Temperatures can reach over 1400 F. in some attics.

Ordinary material may retard heat for a time, but stores a large amount of heat as compared to empty space. More dense, such material is a much better conductor of heat than just air. Its surfaces have a heat ray absorptivity and emissivity of over 90% and radiate heat into the building through the day, and sometimes into the night.



The solution is to use a material which has little substance and whose surfaces will absorb and emit little radiation. Gold or silver foil would be excellent, but tough multiple layers of aluminum, which weigh but 1/4 oz. per sq. ft. are inexpensive and almost as good, with a heat ray absorptivity and emissivity of only 3%.

costs. The building not artificially cooled, needs it even more!

The August 1953 issue of "House & Home" has a very valuable article by A. M. Watkins entitled *"Five Top Priorities for Designing an Air-Conditioned House,"** reprints of which are available from us for the asking.

TRY THIS TEST: Tack or scotch-tape 3 sq. ft. of multiple aluminum insulation (which will be sent free on request) to the underside of a hot roof or ceiling, whether uninsulated, or insulated with ordinary insulation. Step in and out of the protected area beneath the aluminum insulation. The difference will be so marked you will need no thermometer.

HEAT LOSSES THROUGH CELLARS AND CRAWL SPACES

When walls and ceilings are warm, and *floors are cold*, considerable heat is lost. Obeying nature's law that heat flows from warm to cold in every direction by Radiation and Conduction - - the ceilings, walls, furniture, even the dust particles in the air and the people in the room, radiate invisible heat rays to the cold floor, which *absorbs* them at a 90% rate.

There is also heat flow *down* by *conduction*, down the walls, and wherever furniture and people touch the floor.

Still obeying nature's same law, the warmth then travels *down* through the floor by *conduction* to the *surface* below. From that surface, which has 90% emissivity, the heat is radiated downward to the ground below, without temperature, to heat Mother Earth.

GROUND VAPORS

Needed here is a thermal insulation with very low emissivity; which also keeps out ground vapors; which is not affected by dampness; which will remain permanently in place and not tear at the points of nailing; and which can be installed cheaply without the need of expensive supports. *(Multiple sheets of aluminum meet these specifications.)*

The 1955 Guide of the Am. Society of Heating and Air Conditioning Engineers states on page 184, **"The heat transfer through basement walls and floors to the ground is dependent on the temperature difference between the air within and that of the ground, on the material constituting the wall or floor, and on the conductivity of the surrounding earth."**

If scientific, multiple, joist-to-joist aluminum insulation, of full uniform-depth, is installed in ground floors and *crawl spaces* of cold buildings, the heat rays which flow downward in winter will be reflected upward, back to the structure, at a 97% rate. There will be only 3% absorptivity of heat rays. The temperature of the COLD FLOORS which cause COLD FEET will be raised, and FUEL BILLS reduced.

NO "DEAD" AIR CELLS

There is no *such thing* as a "dead" air-cell, or "dead" air-space, as far as heat flow in thermal insulations is concerned; nor even in the case of a perfectly air-tight compartment.

Except for downward flow, convection currents are inevitable with differences in temperature between surfaces, if air or some other gas is present inside.

Furthermore, since air has *some* density, there would be some heat transfer by conduction if *any* surface of a so-called "dead" air-cell were heated.

Finally, radiation, which accounts for 50% to 93% of the heat transfer, would be present and active in any direction.

Even assuming the space to be a vacuum (in which case it would cease to be an *air*-space), heat rays would pass through freely, as they pass through the many million miles of vacuum between the sun and the earth.

SURFACE ROUGHNESS INCREASES CONDUCTANCE

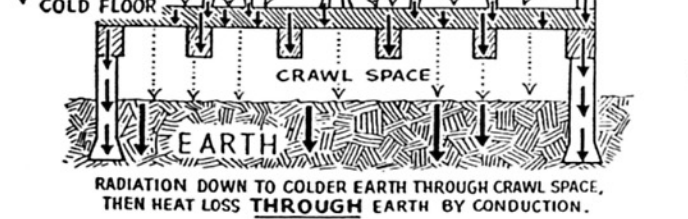
Profs. E. A. Allcut and F. G. Ewens of the University of Toronto, School of Engineering, state in their book "Heat Insulation as Applied to Buildings and Structures," **"Surface conductance increases with the roughness of the surface."**

The 1955 ASHAE GUIDE, page 174 states, **"The heat transfer by convection and conduction is controlled by the roughness of the surface, by air movement and temperature difference between the air and the surface."**

In a booklet entitled *"Wind Velocity Gradients Near a Surface and Their Effect on Film Conductance,"** by F. C. Houghten, Director, and Paul McDermott, Research Engineer of the Laboratory of the American Society of Heating and Air Conditioning Engineers, on page 9 we find,

"The smoother surfaces show a lower coefficient for the same wind velocity and a slight curvature."

"The several curves for the different surfaces studied in the two investigations indicate rather clearly that roughness of surface is the main factor affecting film conductance coefficients for any type of material used in building construction."



RADIATION DOWN TO COLDER EARTH THROUGH CRAWL SPACE, THEN HEAT LOSS THROUGH EARTH BY CONDUCTION.

ELIMINATE COLD FLOORS!

CUT FUEL BILLS! INCREASE COMFORT!

By Reducing Down-Heat Flow Through Crawl Spaces

Scientific Multiple Aluminum Insulation reflects back Radiation up to floor with 97% reflectivity and only 3% absorptivity.

AIR SPACE CONDUCTANCES

"The Conductance of an air space is dependent on the temperature difference, the height, the depth, the position and the character of the boundary surfaces," page 167, the 1955 ASHAE Guide.

As far as *direction* of radiant heat flow is concerned, it makes no difference whether the flow is up, sideways, diagonal or downwards. It is otherwise with convection.

Experimental investigations have been made to find out what *width* of air space adjoining ordinary surfaces and reflective surfaces will give the best insulation value, and how this value is affected by changes in mean temperature and temperature differences of the surfaces of the space.

Radiation is found to be practically independent of the depth of a space, but is affected by temperature difference.

Convection and Conduction are affected by depth of air space and temperature difference, but not at all by emissivity. Direction of heat flow affects convection only.

For horizontal heat flow, including heat flow through wall spaces, the conductances of vertical air spaces bounded by ordinary materials decrease as depth of space increases, until a depth of about $\frac{3}{4}$" is attained; beyond which depth there is slight change. In other words, the larger the depth of a space up to $\frac{3}{4}$", the better will be its insulating value.

On the other hand, and this holds true whether the direction of heat flow is up, down or sideways, the smaller the air space below $\frac{3}{4}$", the greater will be not only the heat flow by Conduction, but also the over-all heat flow or Conductance. The smaller air space is poorer as an insulation. Below $\frac{1}{4}$" depth it deteriorates so badly in insulating value that heat flow through the tiny air space follows the curve of *pure conduction.*

We have already noted the great difference in thermal conductance of an ordinary air space with respect to *direction* of heat flow, up, down or horizontal, namely C 1.32, .94 and 1.10 respectively. (Page 18.)

The difference is even more drastic if the surfaces are changed to *highly reflective* ones, changing the air spaces to reflective air spaces, for instance an air space with an effective emissivity of 5%. These spaces then have a C factor of .5 for upward heat flow, .175 for down flow and .357 for horizontal flow. (R factors: - up, 2.0; down, 5.7; side, 2.8.)

Subdividing even a reflective space into several smaller reflective spaces, but not *too* small, produces further very marked decreases in conductance, as the Westinghouse-Schad tests demonstrated. (Page 26.)

OPTIMUM SPACING FOR ALUMINUM SHEETS

AND VARIATIONS WITH TEMPERATURE DIFFERENCE, MEAN TEMPERATURE AND DIRECTION OF HEAT FLOW

HEAT FLOW SIDEWAYS, Reflective Spaces.

For a *single* reflective space to have lowest Conductance for side or wall heat flow, the optimum width is about 3/4".

If the space is made *smaller* than 3/4", but with the same boundary surface temperatures, the amount of Radiation across it remains the same, and Convection decreases. But Conduction through the air space increases so much more that the *net* result is a higher 'C' factor, i.e. more heat flow across. As the width decreases its Conductance increases.

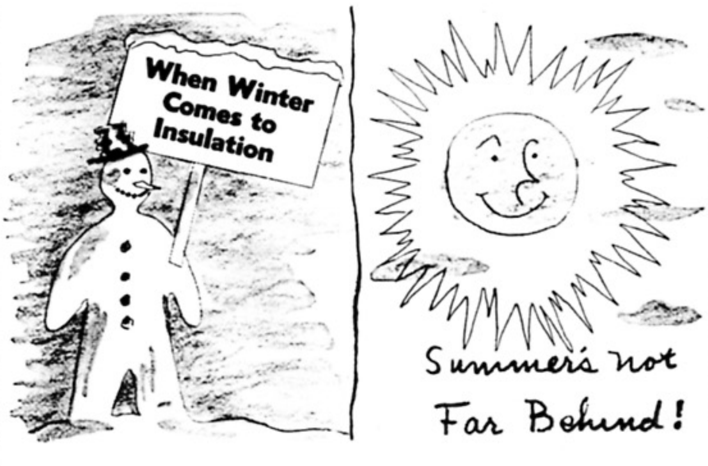
If the space is eliminated, although radiation and convection flow cease entirely, direct conduction between solids results, and even greater heat flow.

It has been estimated that the maximum insulating value, the lowest Conductance, in a space of *fixed* width, for horizontal or wall space heat flow, can be obtained by creating a series of reflective spaces within it, separated about .37 inches apart. Although *each* .37" space has less insulating value than the maximum potential of a single 3/4,' space, nevertheless because of the relatively *larger number* of such .37" spaces resulting from the narrower subdivisions, each *reflective* space has a reduced *temperature difference* between surfaces, which reduces convection as well as radiant heat flow. The result is an efficiency which is the maximum possible. This finds important application in problems involving extreme temperature differences, such as sometimes occur in refrigeration and high temperature work.

Decreasing the space between sheets below .37 inches, (and correspondingly increasing the number of sheets) will unduly increase heat flow by conduction through each narrower space, *decrease* the overall resistance, and *decrease* the insulating value of the space to be insulated.

HEAT FLOW DOWN, Reflective Space Values

If the width of the space is increased up to 8", Conductance will become less, *the greatest decrease occurring in the first inch of space.* There will be a marked difference between 1" and 2", and very little change after 2".



INSULATION for winter warmth and fuel conservation can be very efficient, and also provide coolness and comfort in summer. A building correctly shielded from the summer sun's radiation is considerably cooler, not only by day, but also at night. Protected against winter heat loss and fuel waste, this building warms up faster when there is no great mass of insulating material which also requires heating.

Choosing insulation should be a scientific selection based on physical needs, financial considerations... and above all, on performance. The **RADIATION TABLE** on page 22 shows the heat ray absorptivities, reflectivities, and emissivities of the different materials. It is also important to know their permanency, their permeability to water vapor, and to what extent they foster or retard destructive condensation.

RECENT IMPORTANT CONTRIBUTORS

An important contribution to the knowledge of air space values, both reflective and non-reflective, was recently made by H. E. Robinson and F. J. Powlitch, under the direction of R. S. Dill, chief of the Heating and Air Conditioning Section, all with the National Bureau of Standards Their findings were published by Housing and Home Finance Agency in a booklet entitled "THE THERMAL INSULATING VALUE OF AIR SPACES, Housing Research paper 32."* Our interpretation of some of the significant material contained in this work, follows.

Apart from orientation, the two factors which have significant effect on the thermal resistance value of reflective air spaces are the temperature difference between the bounding surfaces, and the depth of the space.

HEAT FLOW UP,

DOWN & SIDE

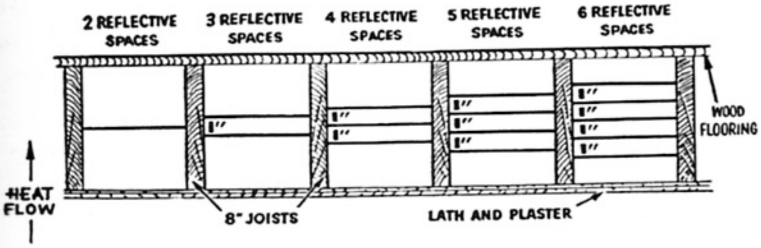
The insulating value of a reflective space in both the up and down heat flow directions *increases* with increasing depth up to about 3 ½", after which further increase seems to have negligible effect. The greatest part of the insulating value comes in the *first inch* of space. In the side heat flow direction, a maximum insulating effect is obtained with spaces about 1 inch in depth; for greater thicknesses, the insulating value first decreases slightly and then increases very slowly for depths of 2" or more. Except for downward heat flow, the changes of insulating value of reflective air spaces with space depth are less than 15%, for depths greater than about one inch.

Considerably more important is the fact that the insulating value of a reflective space with heat flow in any direction, *increases* markedly as the temperature difference between its bounding surfaces *decreases* and causes a significant decrease in convection. It is important because, except for heat flow vertically downward, halving the temperature difference across a space increases its insulating value considerably more than halving its depth may decrease it, provided the final depth is not less than about one inch.

A LAW OF APPRECIATING RETURNS

For this reason, for heat flowing in the up and lateral directions, successive reflective air spaces, one behind the other, follow a law of appreciating returns.

For example, assume heat to be flowing *up* in a group of 8" ceiling joist spaces, with ordinary fixed boundary temperatures (see Illustration). Also assume that the *depth* of the first space is divided in half by an aluminum sheet; that the next space is divided in three parts by two aluminum sheets



centered 1 'a apart; the next space divided in four parts with three sheets centered 1" apart; the next in five parts with four sheets; and the last in six parts with five sheets.

We will find that the insulating value of *each* of the reflective spaces thus formed, follows a pattern of increase as the number of subdivisions of the joist space increases. In other words, *each* 1" reflective air space where the joist space has been subdivided in six parts, has greater insulating value than each similar 1" space where it has been subdivided in five parts; which in turn has greater value than each 1" space where there are four subdivisions, etc. This means of course, that the total insulating value in an 8" joist space of 6 such reflective air spaces is *more than twice* that of 3 such spaces, *more than 50%* better than 4 such spaces.

The explanation is a lower temperature difference across each subdivided space, where there are more subdivisions.

Assuming a space with a *temperature difference of any fixed amount*: – dividing that space into 2 spaces and the temperature difference by 2; or into 4 spaces and the temperature difference by 4; necessarily produces a different and *larger* temperature difference quotient than would a division by 6 or into six spaces. In other words, the more the space is divided, the greater is the *division of the original spread of temperature;* and so **EACH SPACE CARRIES A SMALLER BURDEN OF TEMPERATURE DIFFERENCE.** This means a *decrease* in convection and a corresponding significant increase in the insulating value of the space.

This holds true down to space depths of about 1", below which the diminution in insulating value due to increase in conduction because of lessening the depth, becomes the controlling factor.

A similar type of effect can be noted for lateral heat flow. For vertically downward heat flow this appreciation of value does not obtain.

C and U values on front cover were calculated by the author of *this* booklet on the basis of work done by the NATIONAL BUREAU OF STANDARDS as reported in Housing and Home Finance Agency Research Paper 32.* Structural composition of wall, floor and ceiling and the inside and outside temperatures were assumed the same as those used for typical calculated values by the Bureau of Standards. The ceiling joist space was taken as 7 5/8" deep, wall stud space as 3 5/8", and floor joist space as 9 5/8". (For 5 and 6 space side heat flow, 5 5/8" stud space was used.) The roof was taken as asphalt shingles or roll roofing on 25/32" solid wood sheathing.

For purposes of calculation, air temperatures were assumed to be as follows:

	Heat flow	Inside Temp. °F	Outside Temp. °F	Mean Temp. °F	Temp. Diff. °F
Walls	side	70	0	35	70
Ceilings	up	80	10 (attic)	45	70
Ceilings	down	90	120 (attic)	105	30
Floors	down	65	30	48	35

INFRA-RED HEAT RAYS PIERCE

331 Miles of Dust and Fog

INFRA-RED HEAT RAYS differ from light rays, such as those reflected by a glass mirror. Light rays are visible, and can penetrate only glass, or other transparent or translucent substances.

The infra-red heat rays are invisible. They are largely absorbed by glass mirrors, plaster, wood, brick, etc., but aluminum surfaces TURN BACK, *reflect*, most of these heat rays. This kind of "reflection" has no relationship to the visible *brightness* of the aluminum, and the surface may be just as effective against heat rays when the metal is DULL looking as when it is shiny and BRIGHT.

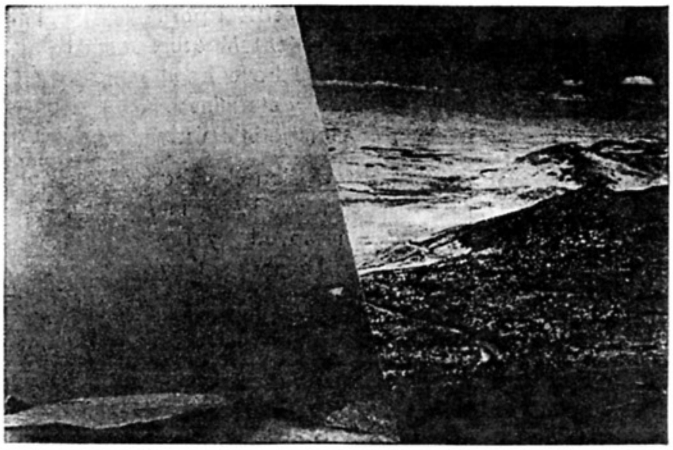
Aluminum foil has a reflectivity ALSO for *visible light*, of over 80%, and therefore is extensively used EXPOSED in factories, auditoriums, etc. It reflects daylight and artificial illumination, and so reduces electric bills.

The American Society of Heating and Air Conditioning Engineers, on page 188 of the Transactions of the 45th Annual Meeting, published a paper by C. S. Taylor and J. D. Edward's, Physical Chemist and Asst. Director of Research of the Research Laboratories of the Aluminum Co. of America, which includes the following:

"The penetrating characteristics of infra-red radiation are illustrated by the aerial photographs which have been taken by Captain Albert Stevens. With infra-red sensitized photographic plates, views of mountains as far as 331 miles distant from the photographer have been taken, though the mountain itself was invisible to the eye because of the intervening haze and fog."

Prof. Wilkes of M.I.T. and Profs. Queer and Hechler of Penn. State College Experiment Station state in *"Thermal Test Coefficients of Aluminum Insulation for Buildings,"**

"A mirror, consisting of glass with a silvered surface on the back of the glass, is an excellent reflector of light but it is a very poor reflector of infra-red radiation corresponding to room temperature. In fact, such a mirror would have about the same reflectivity for infra-red as a heavy coating of black paint.



Courtesy of Eastman Kodak Co.

This composite of ordinary and Infrared photos shows comparative haze penetration of both types of photographic film.

Left: ordinary film using visible light radiation, reproduces the haze-covered terrain as it appeared to the naked eye. Right: Infrared film, sensitive to invisible Infrared Radiation, reproduces what the eye cannot see, by penetrating miles of haze.

"With this in view, it is obviously impossible to judge the infra-red reflectivity or emissivity of a surface by its appearance to the eye. Consequently, in a discussion of reflective surfaces for building insulation, the term brightness has no specific meaning. The terms emissivity or reflectivity definitely define the radiating or reflecting power of a surface and values may be determined for the long wave-length radiation corresponding to room temperature."

Close's book, **"BUILDING INSULATION,"** page 109 says:

"The visible brightness of a surface is not a gauge of its emissivity, for a surface may appear to have lost its reflective value and yet have a comparatively low emissivity as tested by a radiometer or emissivity-testing instrument."

PERMANENT IN THERMAL VALUE

Aluminum combines readily with oxygen to form a *non-progressive* oxide of a fixed amount This means that when a thin coating of *aluminum-oxide* forms, the chemical action stops. A film of this oxide, generally invisible, normally covers the metal. This film *protects* the aluminum from most chemical attack, and is impervious to many reagents. Most important of all, it protects against further attack by oxygen itself, which is ever present in the air, slowly burning up or OXIDIZING, minerals as well as organic matter.

It is often necessary to mix ALLOYS with aluminum, for structural or other purposes, sometimes even at the price of *corrosion*. But aluminum FOIL for insulation purposes is made from *unadulterated* aluminum at least 99.4% pure. It is always covered and protected with *aluminum oxide*. It is this type of pure aluminum which is used for making multiple aluminum insulation.

Prof. Wilkes of M.I.T., in Vol. 31 No. 7 of Industrial and Engineering Chemistry, wrote on page 837:

"The author exposed aluminum foil for 30 days in a furnace at a temperature of 10500 F., and to the eye the surface changed to a dull gray; but the emissivity at room temperature increased only from 0.05 to 0.075 and it still would have made an effective insulator. The conductance value for a vertical air space faced with this gray surface would be only about 5 per cent greater than with new aluminum foil."

One of the few things harmful to aluminum is *actual contact* with WET lime. By installing the insulation with an air space on each side, contact with wet plaster, etc. is avoided, and an additional space is formed to enhance insulation value. In any case, if *multiple* sheets of aluminum were used, and there were any contact, only 1 sheet could be affected, leaving considerable insulation efficiency because of the other sheets. Even the sheet in contact would be affected only at the points which actually touched.

Prof. Wilkes stated in his paper* on the subject,

"In regard to the permanency of the reflective surface, I have no hesitancy in stating that under proper installation conditions, Aluminum Foil Insulation will maintain its efficiency over a long period of time when used as building insulation."

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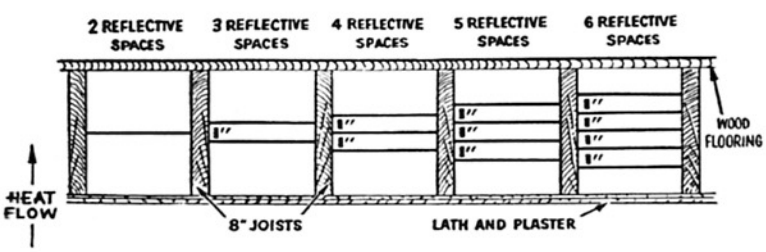

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