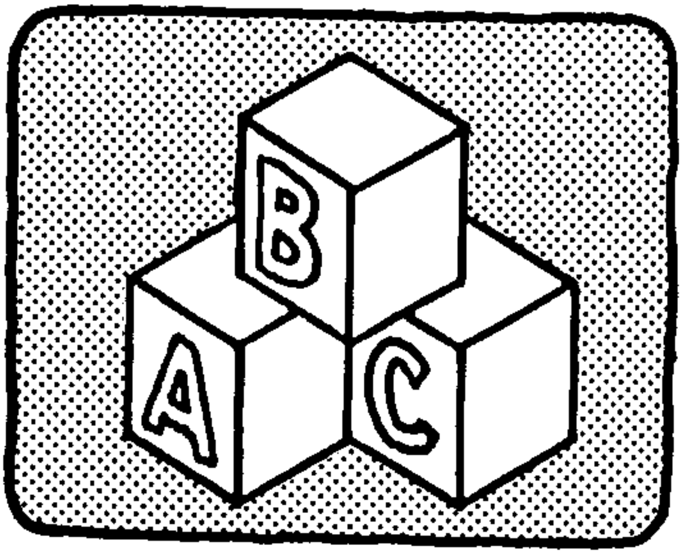
CHAPTER 1
FUNDAMENTALS

This chapter is an introduction to energy concepts and terms.



FUNDAMENTALS

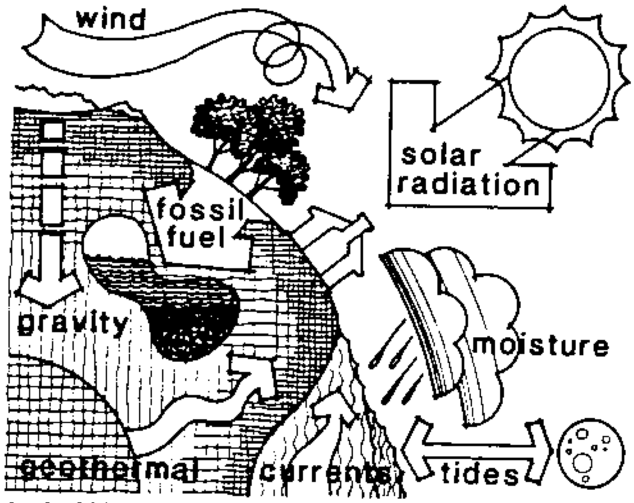
In order to understand the processes at work in a passive solar building, it is important to understand the basics of heat energy and its behavior. A good knowledge of these topics will further aid in understanding the various solar techniques, and a good base in theory can also permit intelligent modification or adjustments to proven techniques.

THE SUN AS A SOURCE OF ENERGY

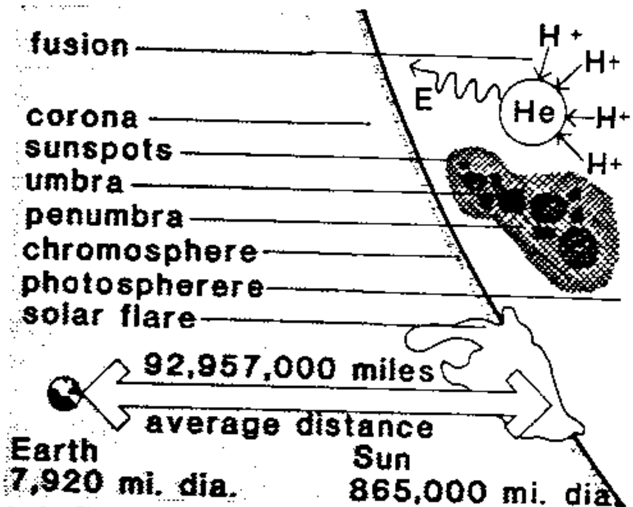
Before examining the concept of heat, it is important to first put concepts into perspective. Energy from the sun manifests itself in many different forms (FIG 1-1). For example, the sun heating the various parts of the atmosphere to different temperatures causes the air movements we call winds. Ocean currents are due in part to similar causes, and hydroelectric energy is energy from the sun that evaporates water from oceans and lakes and then transports it so that it may fall as rain or snow at a higher elevation. The water has gained potential energy by gaining altitude and this energy is released as kinetic energy as the water flows to a lower level.

The fossil fuels owe their chemical energy to a prehistoric photosynthesis dependent on solar energy; buried for millions of years beneath sand, rock and sediment, partially decomposed organic matter is eventually converted through pressure, heat, and aging into fossil fuels such as coal and petroleum or into a by-product of the same process, natural gas.

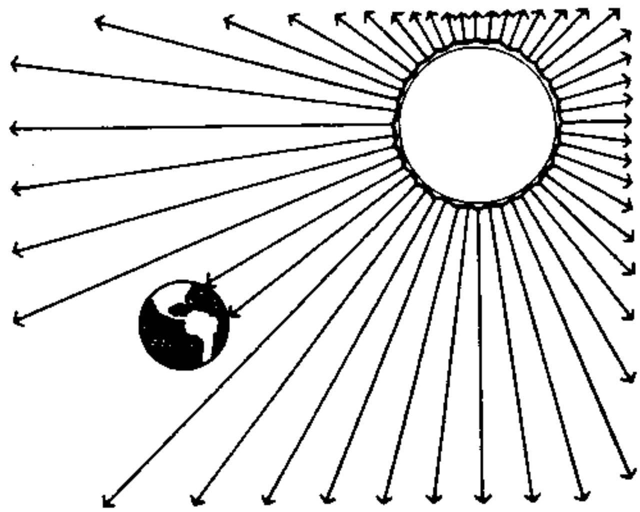
Our sun (FIG 1-2), which provides virtually all of the energy required by life on earth, is a middle-aged, medium-sized star -- Sol -- located near the outer edge of the Milky Way galaxy. The earth orbits around Sol at an average distance of about 93 million miles. This seemingly huge distance is relatively small on the scale of the stars, the next nearest star being many millions of times farther away. The sun is also very much larger than the earth -- containing about a million times the earth's volume. The huge gravitational forces in the sun's interior generate extremely high temperatures, causing hydrogen atoms to combine to produce helium in a process called nuclear fusion. This reaction involves the loss of a small amount of mass which is converted directly into energy and is the same process that makes possible the H-bomb.



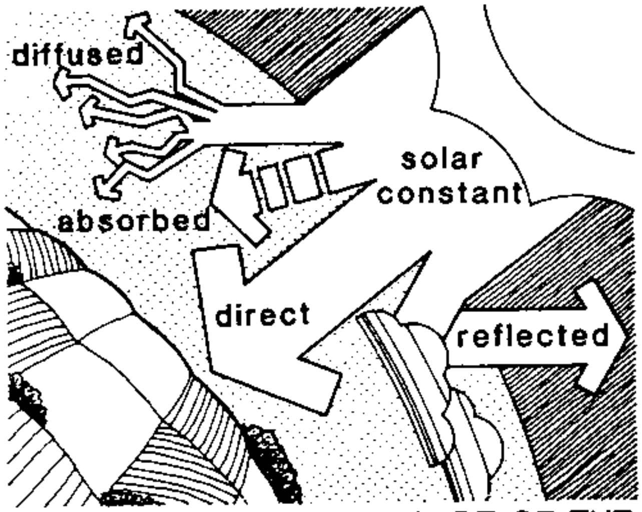
1-1 NATURAL ENERGY MANIFESTS ITSELF IN MANY FORMS



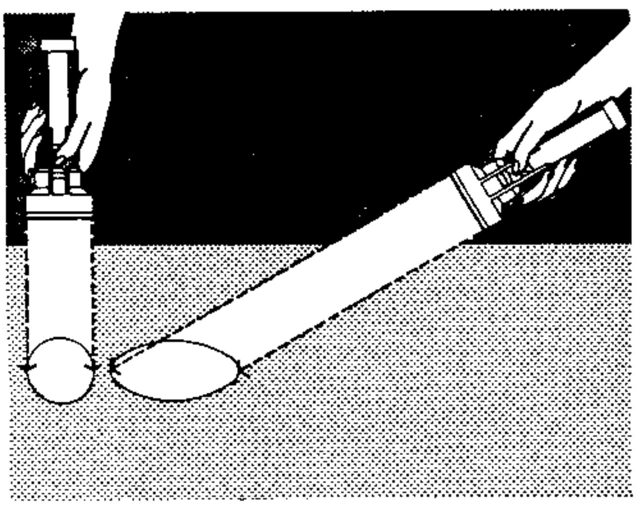
1-2 THE SUN IS A HUGE FUSION REACTOR



1-3 SOLAR ENERGY IS REDUCED WITH DISTANCE



1-4 WE RECEIVE ONLY PART OF THE EXTRATERRESTRIAL SOLAR ENERGY



1-5 ENERGY DENSITY IS MAXIMUM WHEN THE BEAM IS PERPENDICULAR

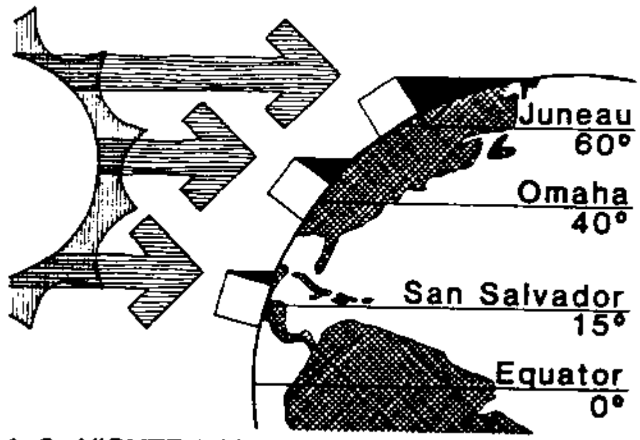
Energy, the product of the nuclear reactions on and in the sun, is radiated into space, mainly in the form of heat and light. It travels outward at "the speed of light", some 186,282 miles per second, taking about eight minutes to reach the outskirts of the earth's atmosphere.

On its journey to earth, the sun's energy changes little, other than weakening (FIG 1-3), until it reaches the outer limits of our atmosphere. Some of the light and heat entering the atmosphere is reflected back into space by clouds and other debris in the air, and some of the energy is absorbed by various components of the air, making the air warmer (FIG 1-4). The energy that makes it to the ground arrives either directly from the sun (the 'direct' or 'beam' component), or after one or more reflections from clouds, airborne debris, or air molecules (the 'indirect' or 'diffuse' component). The diffuse component of the total energy received can range from 10-20% on a clear day to 100% on an overcast day.

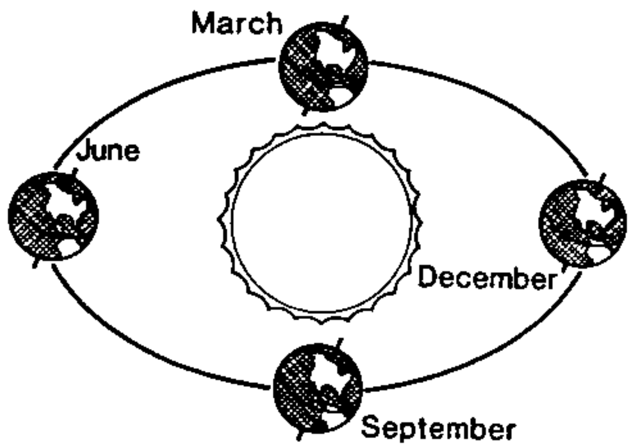
The amount of energy received on the earth's surface is also affected by the angle at which the beam component arrives (the diffuse component is coming from all unshaded directions). This can be compared to the beam of a flashlight, held vertically, shining onto a horizontal table top. A given amount of energy is spread over a given area (FIG 1-5). If the flashlight is moved so that the beam strikes the table at an angle, the area where the light strikes the table increases in size. Since the same total energy is being delivered to a larger area, there is less energy per square inch of table top where the light is shining. As the flashlight is moved further from the vertical position , the beam dims as it spreads.

Several factors affect the angle of sunlight coming to earth. The normal progress of the sun through the sky is the most obvious. Also, sunlight arrives at lower angles at higher latitudes (FIG 1-6). This latitude effect is complicated by the fact that the earth's axis is inclined, or "tipped", approximately 23 degrees from vertical, the direction at right angles to the plane in which the earth orbits the sun. The revolution of the earth around the sun causes the northern half of the earth to lean toward the sun at one point in the orbit, and to lean away exactly one-half orbit (one-half year) later (FIG 1-7). When the northern hemisphere is tipped toward the sun, the middle north latitudes receive solar energy more nearly head-on, and, therefore, intercept more energy per square foot than the southern hemisphere, which is tipped away. This, of course, explains the changing seasons. In the example, the northern hemisphere is experiencing summer, and the southern hemisphere winter.

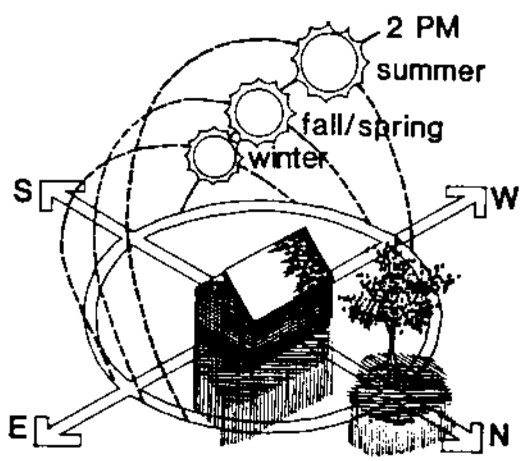
Receiving sunlight "head-on" means the sun is higher in the sky, or more nearly directly overhead, as in the flashlight example; in the summer, the sun seems to pass more nearly overhead, while in the winter, its path is low in the southern sky (FIG 1-8). The farther north, the lower the winter sun's path: at some northern latitudes the sun will not rise for part of the winter. In the southern hemisphere the situation is similar, though reversed -- the sun is low in the northern sky in June.



1-6 HIGHER LATITUDES HAVE LOWER SUN ANGLES



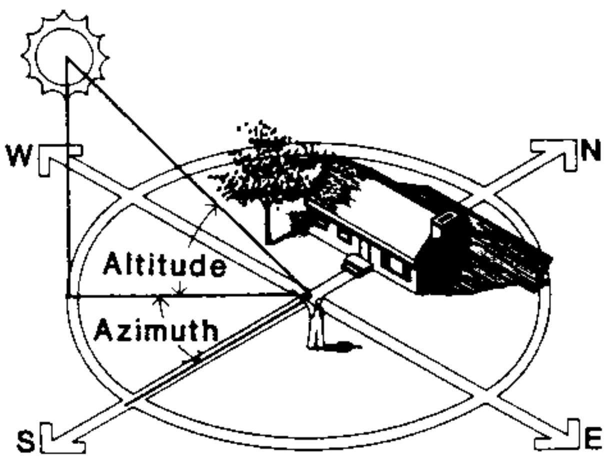
1-7 EARTH TILT IS RESPONSIBLE FOR CHANGING SEASONS



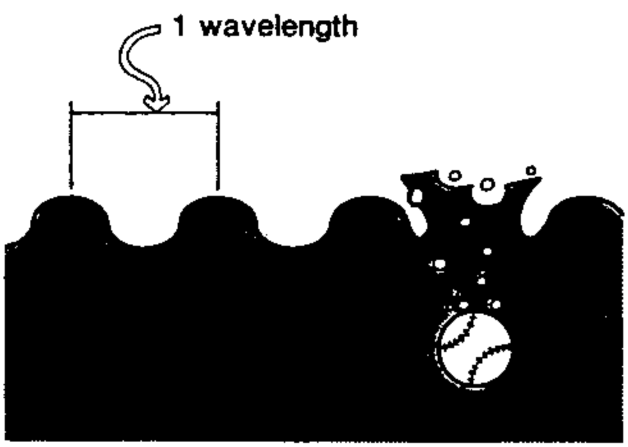
1-9 SEASONAL SUN PATHS

The position of the sun in the sky is measured by two angles -- altitude and azimuth (FIG 1-9). "Altitude" is a measure of how "high" the sun is. An arm pointed directly at the sun and dropped to a horizontal position has moved through the sun's altitude angle. Kept horizontal and swung to true south, the arm moves through the sun's second position angle -- the "azimuth" angle, or the variation from true south.

It is the sun's maximum daily altitude -- which occurs at "solar noon" -- that changes with the seasons, a fact which takes on great importance in designing a workable solar house.



1-9 THE SUN'S POSITION CAN BE DETERMINED BY TWO ANGLES



1-10 WAVELENGTH IS THE DISTANCE BETWEEN CRESTS

SOLAR RADIATION

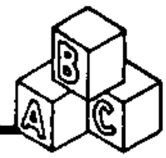
Solar energy is a form of "electromagnetic radiation", which means that the energy has wave-like properties allowing it to travel in the vacuum of space. Wave-like properties include wavelengths -- the distance from one wave crest to the next (FIG 1-10). Electromagnetic waves differ from pond waves in that the former need no physical material to travel in.

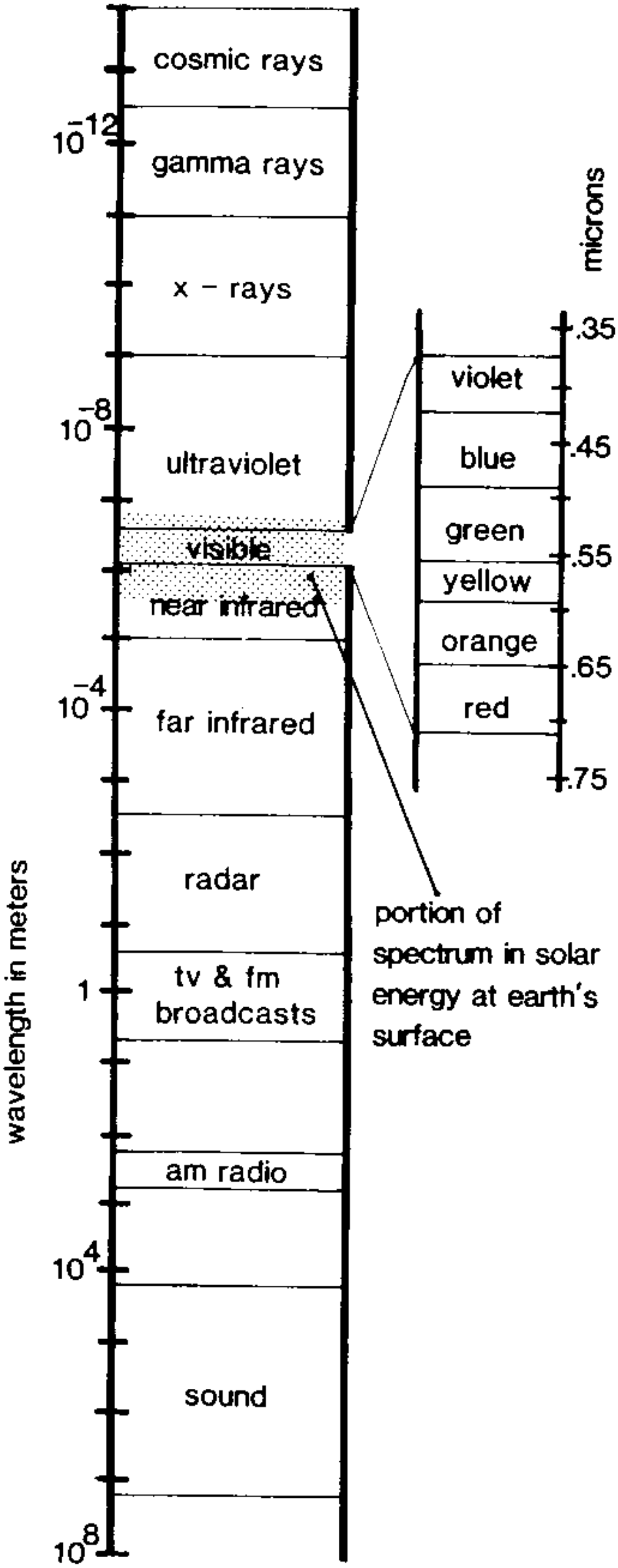
Electromagnetic waves of various wavelengths comprise the "electromagnetic spectrum" (FIG 1-11). Energy emanating from the sun is a collection of wavelengths, all concentrated in a small span of the electromagnetic spectrum called the "solar spectrum".

Energies with different wavelengths can produce different effects, e.g., eyes are directly sensitive to only the tiny portion of the entire electromagnetic spectrum with wavelengths between about 0.35 microns and 0.75 microns (micron is a millionth of a meter). "Visible light" is the term given to this band of energy, which is further divided into smaller ranges of wavelengths. Violet and blue are the shortest wavelengths seen. Red is the longest. Electromagnetic energy with wavelengths longer than red are called "infrared", and are sensed as heat from the sun, a radiator, a hotplate, etc.

The greatest portion of the electromagnetic spectrum is not directly detectable by the human body, however, it is evidenced through the use of various devices, e.g., television broadcasts. On the other end of the visible spectrum are ultraviolet light, X-rays, and gamma rays, all of which are harmful to life in large doses.

As solar radiation passes through the earth's atmosphere, certain components of air -- mainly ozone, carbon dioxide, water vapor, and nitrogen -- absorb specific wavelengths of energy, or small





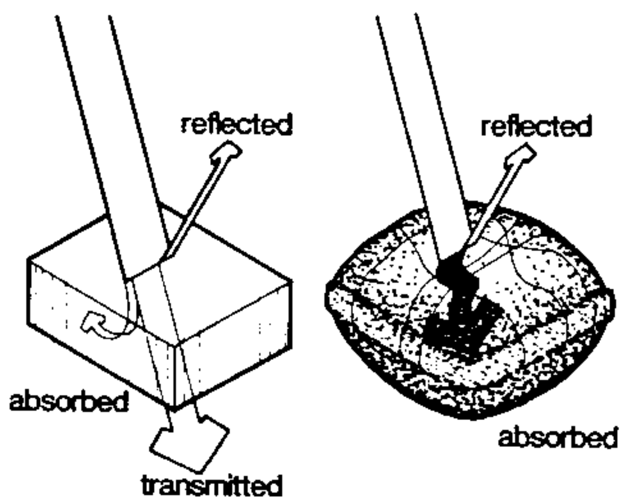
1-11 THE ELECTROMAGNETIC SPECTRUM

bands of wavelengths. Thus, the spectrum reaching the ground is quite different from the solar spectrum in space. Because most of the X-rays and other short wavelengths are eliminated along with the longer part of the infrared, the solar energy finally reaching the ground, consists almost totally of visible light, and what is called "near infrared" radiation.

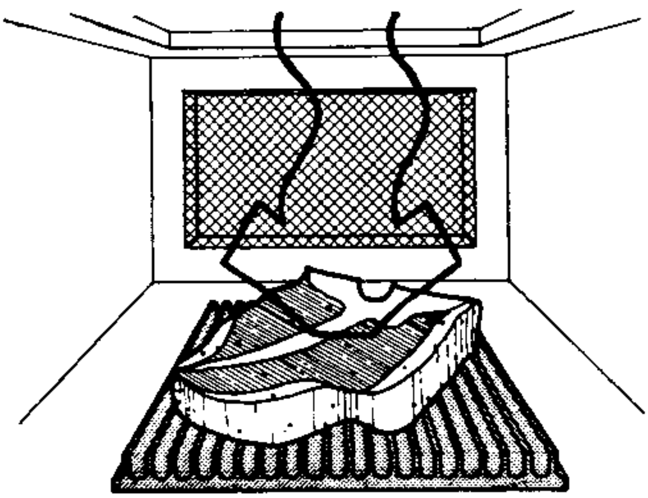
Because the actual amount of solar energy reaching the earth depends not only on complicated but predictable factors like time of day, season, and latitude, but also on very unpredictable factors like weather, solar radiation is usually not predicted by calculation. Rather, tables based on actual measured values averaged over a number of years are used. Tables can be found for many U.S. locations, sometimes with other variables, such as data for vertical and tilted surfaces, hourly solar radiation, etc.

REFLECTION, TRANSMISSION, ABSORPTION

Only three things happen to solar radiation when it encounters a physical material: 1) it can be transmitted through the material, e.g., glass or air, 2) it can be reflected by the surface of the material, e.g., mirrors, or 3) it can be absorbed by the material (FIG 1-12) . Typically, a

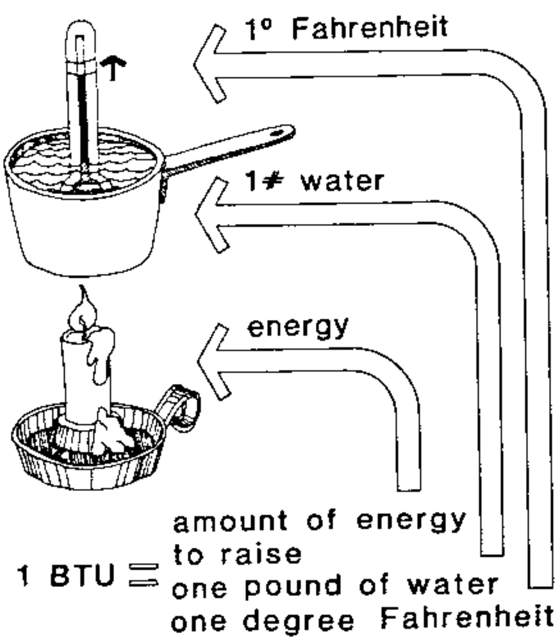


1-12 ABSORPTION, REFLECTION, AND TRANSMISSION DIFFER WITH MATERIAL combination of all three things happen. For example, a pane of clear glass will transmit the majority of any visible light energy falling on it, but it will also reflect and absorb small portions of the energy. Infrared energy, however, is mostly absorbed, with smaller amounts transmitted and reflected. Ordinary glass has a high transmittance for visible light, but lower transmittance for infrared. Accordingly, a mirror has a high reflectance (for visible light), and a lump of charcoal -- which does not reflect or transmit much visible light -- has a high absorptance.



1-13 ABSORPTION OF RADIANT ENERGY PRODUCES HEAT

When radiation energy is reflected or transmitted, it continues unchanged until it encounters another body. Energy that is absorbed, however, undergoes a very basic change -- it becomes heat, which is why infrared radiation is identified with heat. The human body absorbs large amounts of infrared radiation, which acts to raise the temperature of the skin. In reality, however, any type of electromagnetic radiation which is absorbed by a material is converted to heat, e.g., the water in food cooking in a microwave oven has high absorptance for the wavelength being used (FIG 1-13). Heat, then, is a form of energy that is internal to a substance in the agitation of its atoms or molecules. Materials which contain a large amount of heat energy have very "excited" molecules or atoms.



1-14 BRITISH THERMAL UNIT

HEAT AND TEMPERATURE

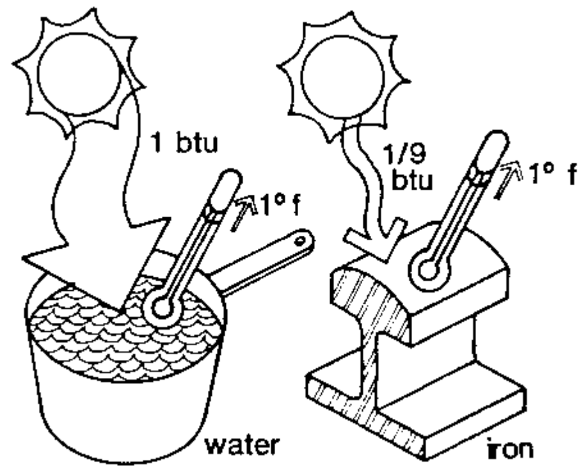
A confusing concept for many people is that heat and temperature are not the same thing. Heat is a measure of energy, while temperature is a measure of the molecular agitation caused by the energy.

HEAT UNITS

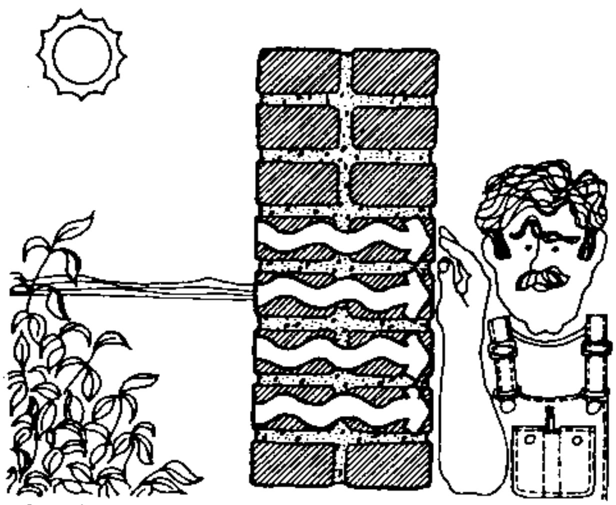
There are two common units for the measurement of heat energy: the British Thermal Unit, or btu and the calorie. A btu is the quantity of heat required to raise the temperature of one pound of water by one Fahrenheit degree (FIG 1-14). The calorie is the quantity of heat needed to raise the temperature of one gram of water by one Centigrade degree. (Note that the Calorie -- with capital "C" -- which is used in dietary terms is equal to 1000 calories). It should be noted that heat and temperature are not the same.

SPECIFIC HEAT

When a material absorbs heat, it gets warmer, unless it melts, boils, or decomposes. However, two different materials, each absorbing the same amount of heat energy, will not necessarily show the same rise in temperature (FIG 1-15). For example, if a pound of water and a pound of iron each absorb one btu, the water temperature goes up by one degree Fahrenheit, while the temperature of the iron goes up by nine degrees Fahrenheit. Iron has a smaller heat capacity than water, since only 1/9 btu will raise a pound of iron one degree in temperature, while nine times as much heat -- 1 btu -- is required to produce the same change in water. This number -- 1/9, or 0.11 -- is called the Specific Heat of iron. Specific Heat is expressed in units of btu/^{o}F-lb. The Specific Heat of water is 1.0, very high compared with most materials. Water's high heat capacity makes it a very good heat storage material in a passive solar home.



1-15 SPECIFIC HEAT



1-16 CONDUCTION

HEAT TRANSFER

In some ways, heat behaves like a fluid in that it has a natural tendency to "flow" from high to low, the high and low here referring to temperature. This natural flow from warm to cold is achieved by three distinct mechanisms: conduction, convection, and radiation.

CONDUCTION

If one side of a brick wall is warm it means that the molecules in the bricks are more excited or agitated on the warm side than other, cooler parts of the bricks (FIG 1-16). These "warm" molecules can pass on some of their energy by physically "bumping into" neighboring cooler molecules, thereby agitating them. Heat energy can be passed on this way, molecule to molecule, until eventually the opposite side of the wall becomes warm. This kind of heat movement is called conduction.

The physical properties of some materials are such that this conduction process proceeds very efficiently with little opposition to the heat flow. These materials, including most metals, are called good thermal conductors. Other materials offer high resistance to heat conduction, and are poor thermal conductors. They are called thermal insulators.

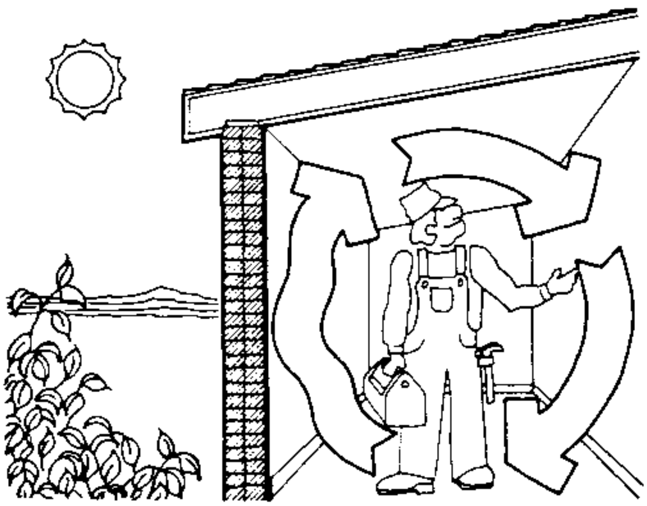
A way to measure the ease with which heat conducts through a material is called thermal conductance, or "U value". The U value of a material is the number of btus of heat which will conduct through a one square foot section of the material in one hour, if there is a one degree Fahrenheit temperature difference between the two sides. The units of a U value, then, are btus per hour per square foot, per degree Fahrenheit. The U value refers to a specific thickness of material -- if the thickness of the material is doubled, the thermal opposition is doubled, and the conductance is one half the previous value. For this reason, conductivity values should identify the U value for a one-inch thickness of material. The U values of other thicknesses of the same material can be found by dividing the conductivity by the thickness in inches.

A more familiar measure of the conduction properties of materials is the "R value", a measure of the resistance, or opposition to heat flow. It is the reciprocal of the U value:

$$R=1/U, \text{ and } U=1/R.$$

R values are useful because they can be added "in series"; the total R value for a wall made up of several different layers of different materials is the sum of the R values of each layer.

Values for conductance, conductivity, and resistance of common materials can be found in Appendix 3 and Chapter 5.


1-17 CONVECTION

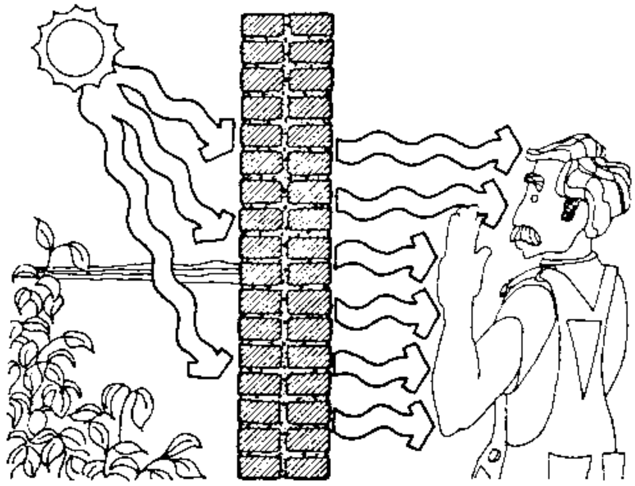
CONVECTION

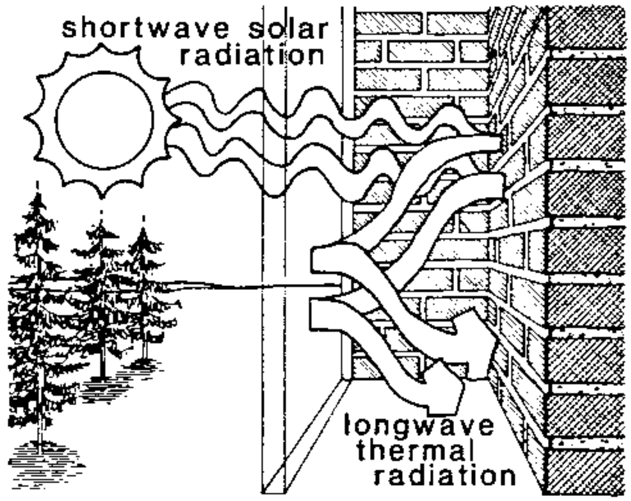
If the inside surface of the brick wall is warmed by conduction of heat from the outside, air next to the inside surface will also be warmed by conduction (FIG 1-17). Air expands as it is warmed, which makes it lighter. As light, warm air rises, it is replaced by cooler, heavier air. If the wall is one side of a closed room, the warm air rises to the ceiling, where it may lose some of its heat (by conduction to the ceiling) and start to sink. The heat is being moved from the inside wall surface to other parts of the room by convection -- the transfer of heat by the physical movement of a warm substance. This example is one of "natural convection", since the movement is due solely to natural forces. "Forced convection" occurs where warm air (or water, or other substance) is moved by the use of a pump, e.g., warm air furnaces with blowers distribute heat by forced convection.

RADIATION

The third kind of heat transfer is electro-magnetic radiation -- the mechanism by which heat from the sun reaches the earth.

All objects radiate energy. The amount and kind (wavelength) of radiation depends on two things -- the temperature of the object and its emissivity. Warmer surfaces radiate more energy at shorter wavelengths. This is why it is possible to feel the warmth of a brick wall at a distance, independent of conduction and convection effects (FIG 1-18). Hot water or steam "radiators" give a feeling of warmth largely due to radiation, although conduction and particularly convection play a role also. Studies have shown that a source of radiant heat, such as a warm wall, will give a sense of comfort even at air temperatures which would otherwise feel chilly. The old pot-bellied stove is another example of this effect.


1-18 RADIATION

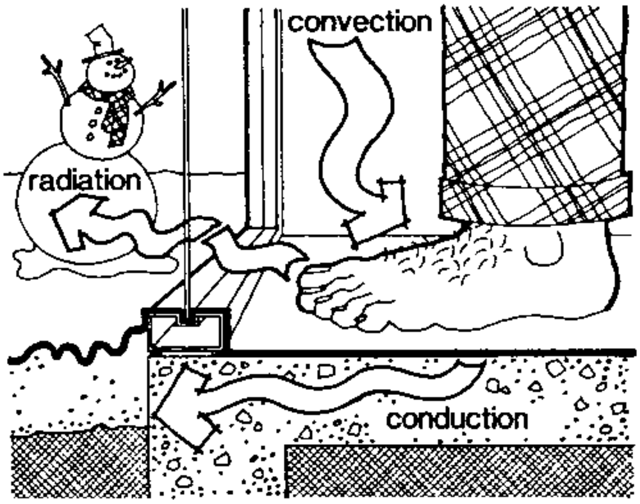


1-19 GREENHOUSE EFFECT

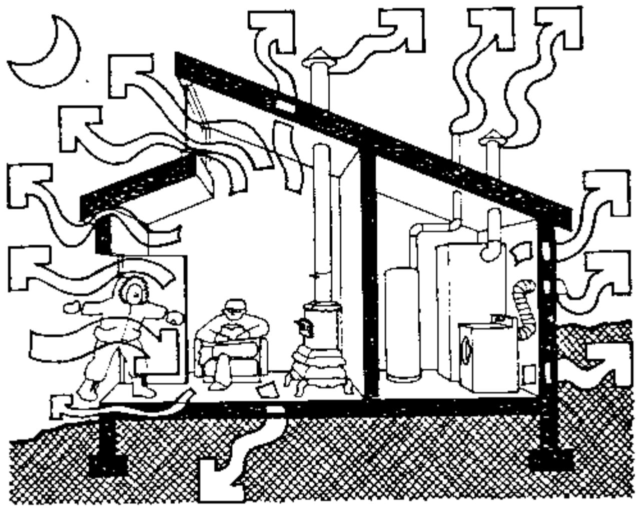
Emissivity is a property of a surface. An emissivity value of 1.0 means that 100% of the possible radiation at a given temperature is radiated by the surface. Similarly, an emissivity value of 0.5 means that only 50% of the possible radiation at the given temperature is radiated.

GREENHOUSE EFFECT

As noted previously, ordinary window glass is relatively transparent to visible light and more opaque to infra-red, or heat radiation. When sun energy, which is mostly in the visible region, encounters a pane of glass, most of the energy is transmitted. If the light then strikes a surface where it is absorbed, the surface will be heated (FIG 1-19). This hot surface will radiate infrared energy. This heat radiation cannot pass through the glass and is reflected back into the space between the glass and the absorbing surface. (In practice, some of the infrared energy radiated by the wall will be absorbed by the glass, heating it). This is known as the greenhouse effect, a very important mechanism in the operation of a solar house, and special glasses and glass coatings have been developed to enhance this effect.



1-20 HEAT IS OFTEN MOVED BY ALL THREE MEANS


1-21 HEAT LOSS PATHS

LOSSES AND GAINS

Ideally, a home should maintain a constant comfortable indoor temperature regardless of outside conditions. Indoor temperature in a home is determined by the balance of the various heat flows into, out of, and within the building. Heat flows which tend to raise the temperature in a building are called gains, and flows which tend to lower the temperature are called losses.

On a cold winter day, a heated home will lose heat to the outside because heat flows from warm to cold by conduction, convection, and radiation (FIG 1-20). To maintain a constant indoor temperature, this loss must be replaced by an equal heat gain, either from the sun, a furnace, or other internal sources.

HEAT LOSSES

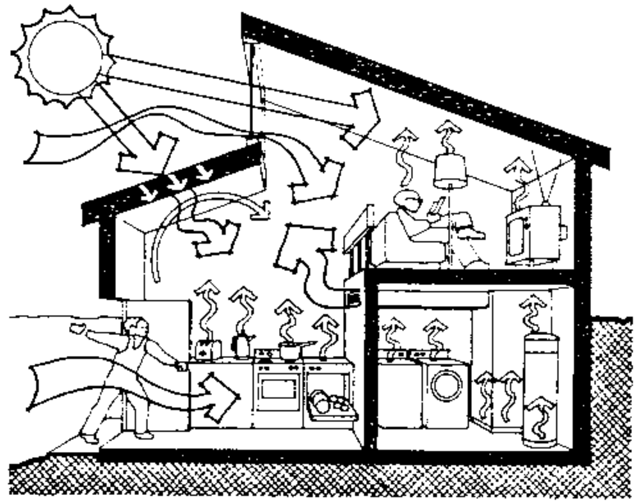
Heat losses are of various types and causes (FIG 1-21), including air leaks, called infiltration losses, and conduction losses through exterior walls, ceilings and roofs, windows, doors, slabs, and basement walls. In a reasonably well constructed house, half the winter losses are due to infiltration and half are due to conduction through exterior surfaces although this may vary.

Infiltration is a form of convection, and includes air movement through cracks and seams, as well as through open doors and windows. Infiltration, measured in air changes per hour (ACH), reflects how many "housefuls" of air leak into or out of the structure in an hour. Values can be as high as 3 ACH and even higher in loosely-constructed homes.

Despite the potential for heat loss through infiltration, very low infiltration rates are not desirable. Problems with odor control and moisture buildup can occur with infiltration rates below 0.4 ACH.

HEAT GAINS

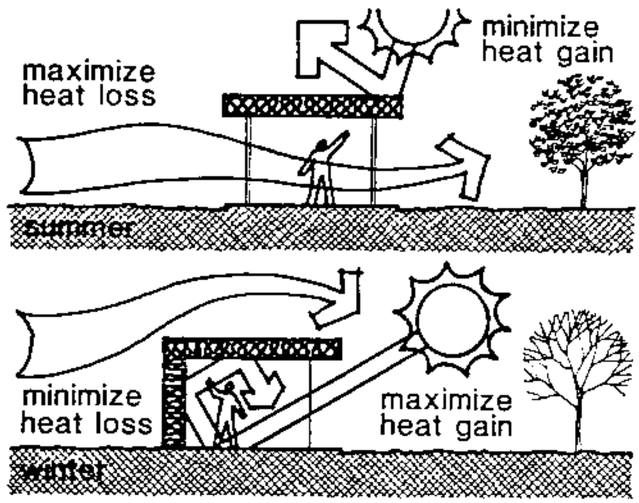
Heat gains in winter include solar (intentional and otherwise), conventional home heating equipment such as a gas furnace (called "auxiliary heat"), and what are called "internal gains" (FIG 1-22). Internal heat gains are due to the actual operation of the home, and come from lights, appliances, cooking, bathing, and from the body heat of the occupants themselves. Internal gains for a typical family of four can amount to as much as 80,000 btus per day. Internal heat gains are free btus in a sense, since this heat is really a by-product of some other process.



1-22 SOURCES OF HEAT GAIN

SOLAR HEATING

Another source of "free" energy is the sun (free in the sense that there are no ongoing fuel costs). Every btu gained from the sun is one less btu that must be supplied by the furnace or other auxiliary heating unit. Obviously, a most important factor in an energy efficient house -- solar or otherwise -- is minimum winter heat loss. It is folly to build a loose, poorly insulated house, with the idea of letting solar energy make up the difference. A solar house should begin as a well-constructed, well-insulated house. This will insure maximum benefit from every square foot of solar window.



1-23 PASSIVE SOLAR PHILOSOPHY: DESIGN WITH NATURE

SOLAR DESIGNS

There are an infinite number of ways to achieve a useful heat gain from solar energy. The most practical of these tend to group themselves into categories according to details of energy collection, storage, and transport. The first broad distinction between types of solar heat systems are the so-called active and passive types. The classical definition of a passive solar system is one in which all energy flows are caused by natural forces. Active systems, on the other hand, are usually characterized by the use of pumps or fans to aid in the transport of energy.

Between these two pure classes are "hybrid systems", which use some elements of both types.

PASSIVE SOLAR SYSTEMS

Purely passive solar energy systems operate independently of any outside power source other than the sun: the use of fans and pumps is downplayed or eliminated (FIG 1-23).

Within the class of passive systems, a number of basic types can be identified, usually based on different configurations of collection, storage, and distribution elements. There are, however, some basic characteristics common to all types.

In Nebraska, in winter, the potential for solar heat gain exists for only roughly one third of the 24 hour day. Homes, however, lose heat over the entire day. While it is a relatively easy matter to design a system which would admit the proper amount of solar energy for the immediate needs of a home while the sun is shining, the goals in a solar home should be: 1) to admit significantly more solar energy than is immediately required for space heating, and 2) to store the excess for use during the time that the sun is not shining.

The most obvious feature of a solar concious house is its unique use of glass. To capitalize on the solar energy available in the winter, substantial areas of south-facing glass are a solar standard. Unwanted summer heat gains and winter heat losses are avoided by the reduction of the number and size of windows on the west, east, and north.

The storage medium in a passive system is called "thermal mass". It is usually a material which is capable of storing large quantities of heat in a relatively small volume without becoming excessively hot, i.e., a substance with high specific heat properties. Concrete, brick, masonry materials, and water are commonly used as thermal mass. The function of thermal mass in the system is to absorb excess solar energy during the day, store it as heat, and release it to the air when the inside room temperature begins to fall. Thus, thermal mass inhibits, or "damps out" temperature fluctuations in the air.

In a successful solar house, the glass area and the thermal mass work in harmony. One is of limited use without the other.

SOLAR PERFORMANCE

There are a number of quantitative measures involved in solar design. Among these are some climatic variables which affect thermal performance (heating and cooling degree-days, and outdoor design temperature). The remaining measures to be discussed are calculated values which describe various aspects of thermal or solar performance.

HEATING DEGREE-DAYS

A home in a cold climate will lose more btus of heat through a winter season than will an identical home in a more moderate climate, because of the larger average temperature difference between inside and outside for the cold climate house. The larger the average temperature difference, the faster the rate of loss. Thus, the performance of a particular solar design is very dependent on its geographical location and related climate.

One of the most common and useful measures of winter climate is that of heating degree-days (FIG 1-24a). Assume the average temperature over a one day (24 hour) period in Ogallala is 12°F. To maintain living space at 65°F (ignoring internal gains), heat must be supplied to sustain an average temperature difference of 53 degrees for one day. In weather terminology, this translates into 53 degree-days of heating for that day. The degree-day values for each day in a month are totaled to derive the degree-day total for that month. Degree-day totals for an entire heating season can be similarly calculated. (Temperatures above 65°F are ignored for these calculations, since under such conditions, no heating is needed). Monthly and heating season degree-day tables listing values which are averages over a number of years for various locations are available (Appendix 2).

From these it can be seen that even within Nebraska the severity of winter climate varies considerably (FIG 1-25).

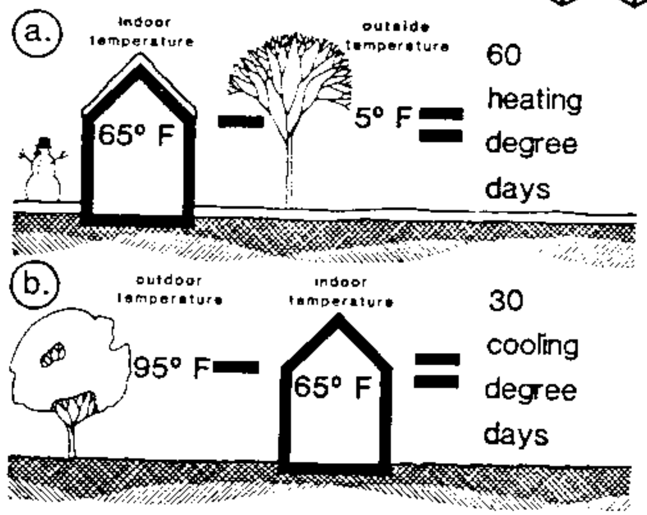
The 65°F indoor temperature in the example is called the "base temperature" for the degree-day calculations. Although other base temperatures are sometimes used, the 65°F base is most common, and will be most readily available. 65° was chosen as the base temperature because, in a typical house-family combination, the internal heat gains (which were ignored in the example) will account for about 7 degrees of indoor heating -- bringing the actual indoor temperature to 72°F. Although 72°F is historically considered normal room temperature, recent trends in lower indoor temperatures and higher levels of insulation make this approximation questionable.

COOLING DEGREE-DAYS

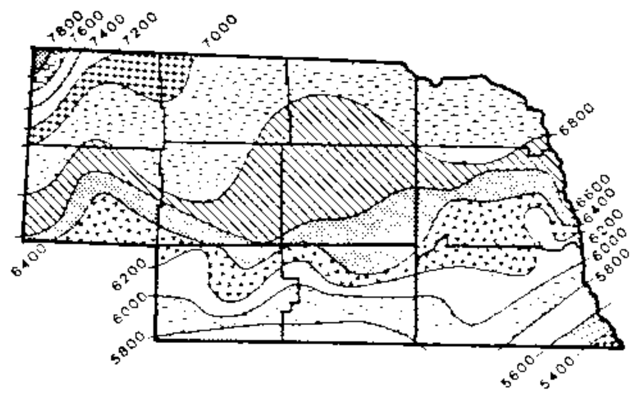
In the cooling season, the severity of the summer temperatures is specified in the degree-day format also, as cooling degree-days. Their calculation is analogous to that of heating degree-days (FIG 1-24b, 1-26).

DESIGN TEMPERATURE

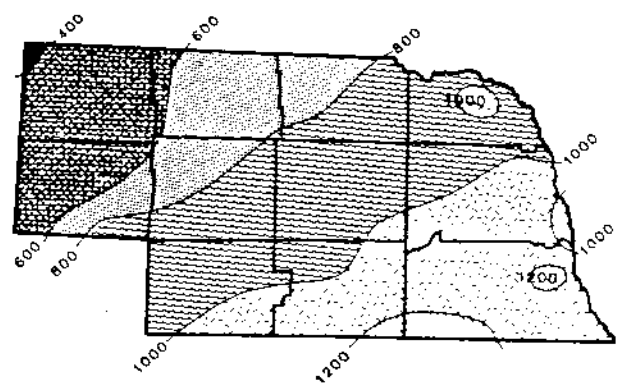
Every locale also has a specific outdoor winter design temperature, the description of how low the outdoor temperature will get with any regularity. For example, a 97.5% outdoor design temperature of -3°F for Omaha means that, on the average, the temperature will be below -3°F only about 2.5% of the time during the heating season.



1-24 DEGREE DAY



1-25 NEBRASKA HEATING DEGREE DAYS



1-26 NEBRASKA COOLING DEGREE DAYS

FUNDAMENTALS

BUILDING LOAD COEFFICIENT (BLC)

Sometimes called heating load coefficient (HLC), the building load coefficient (BLC) is a measure of how easily the structure loses heat. It is the number of btus lost by the house per degree-day, or btus per day per degree temperature difference between inside and outside. From this number, the total number of btus lost in a month or season can be found by multiplying by the total degree-days for that month or season.

DESIGN HEATING LOAD (DHL)

The design heating load (DHL) is the number of btus lost from a building per hour, when the outdoor temperature is at the outdoor design temperature. Because heat must be replaced at the same rate at which it is lost in order to maintain a constant indoor temperature, the design heating load is used to specify the size of the furnace or other heating unit in a conventional home.

LOAD-COLLECTOR RATIO (LCR)

The load collector ratio (LCR) is a measure of how much of the building load must be handled by each square foot of solar glazing. It is the ratio of the building load coefficient (BLC) to the number of square feet of solar aperture, i.e., solar windows.

SOLAR HEATING FRACTION (SHF)

The solar heating fraction is the fraction of the building's heating requirement supplied by the solar system over a specified period -- usually a month or an entire season. The use of the solar heating fraction (SHF) has fallen in disfavor in some circles because the solar system is credited for offsetting a heating load for which it is partially responsible. That is, adding solar glazing to a home will normally increase the heating load, due to the increased glass area of low R value. The solar gains from a system must compensate for these losses, in addition to offsetting part of what would be the load of a non-solar house. If a solar system only provided enough heat to offset its own losses, it would still get credit for a significant SHF, although the home owner is no better off than with an equivalent non-solar house.

SOLAR SAVINGS FRACTION (SSF)

A more accurate measure of solar performance is the solar savings fraction (SSF), which specifies the fraction of auxiliary heat (from furnaces or other space heating units) which is saved in the solar house, in comparison with an identical house with the solar glazing replaced by a thermally neutral surface (one through which no heat is lost or gained).

The strength of this measure is that a comparison is made with an identical non-solar house. In this case, if the solar system were able only to offset its own losses it would be the equivalent of a neutral surface; the solar and non-solar homes would have identical performance, thus leading to a solar savings fraction of zero for the "solar" house.

THERMAL INTEGRITY FACTOR (TIF)

In the final analysis, that solar house is best which demands the least auxiliary heat, and a measure of auxiliary heat requirements is needed to be able to compare houses of different sizes and in different climates. The thermal integrity factor (TIF) is a measure of the number of btus of auxiliary heat required per hour for each square foot of floor area in the house, for each degree-day of heating requirement. The real strength of this measurement is that direct comparison between solar and other energy efficient but non-solar houses (earth sheltered, super-insulated, etc.) can be made directly.