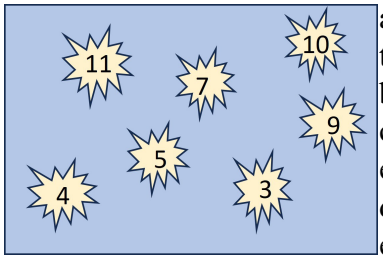
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VIII – Energy, Heat and Temperature

The most basic function of a passive solar greenhouse (PSG) is to provide enough heat to keep the interior within an acceptable temperature range for plant growth year-round. To understand how this works, we need to review the physical principles of energy, heat, and temperature, and how they interact within a greenhouse environment.

Heat and Temperature - What's the Difference?

An object's temperature is one of the variables we use to help us measure how much heat it contains. The terms are often used interchangeably, but heat and temperature are not the same thing. The amount of heat is the total kinetic energy of all the molecules in a substance added together, while temperature is the average kinetic energy of those molecules. Let's check our understanding of this basic concept. In the box with seven molecules the number represent the amount of kinetic energy of each molecule. The amount of heat in the box equals 49, whereas the temperature of the box is 7. Thus, a bathtub of water at 40°F contains much more total heat than a coffee cup at 100°F, because the tub contains far more molecules, even though its temperature is lower than the cup of hot coffee. This distinction is important when comparing thermal mass materials or evaluating how much energy a greenhouse can store.



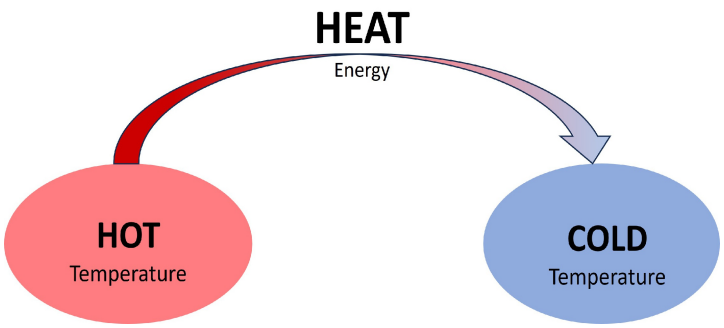
We measure **temperature** using three scales:

- Celsius (°C): Freezing point of water at 0°C, boiling at 100°C.
- Fahrenheit (°F): Freezing point at 32°F, boiling at 212°F.
- Kelvin (K): Absolute scale used in science; zero is absolute zero, the point where a substance has no molecular kinetic energy. Absolute zero corresponds to -273°C (-459.7 °F). A degree on the Kelvin scale is the same as a degree on the Celsius scale.
  NOTE: the freezing and boiling points of water are valid at sea level.

Heat is also measured in three different units:

- Calories (c): Energy required to raise 1 gram of water by 1°C.
- Kilocalories (C): 1,000 calories.
- British Thermal Units (BTU): Energy required to raise 1 pound of water by 1°F.

Under normal conditions, heat always flows from warmer objects to cooler ones until equilibrium is reached. The relative temperature of something to its surroundings (not the amount of heat it contains) determines the direction of heat flow! This is why insulation and design features that slow this flow are so important in a PSG.



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How Heat Moves: Conduction, Convection, and Radiation

Heat energy can move from one object to another by the processes of Conduction, Convection and /or Radiation. Most of us are familiar with heat transfer by conduction and convection. When we touch a hot cup of coffee, it transfers heat to our hands through the process of conduction. In a hot room with no air conditioner, we might turn on a fan (if we have one) to blow air across our skin to cool off by the process of convection. Or we can start a fire in a wood stove or fireplace to warm the room by radiation.



1. Conduction is heat transfer within or between solids and liquids through direct molecular contact. For example, a metal spoon quickly warms when placed in cup of hot coffee because metals conduct heat well. Materials like wood or plastic conduct poorly, making them good insulators.

Two factors determine the rate of heat flow between two objects. First is their difference in temperature which can be observed in heating/cooling graphs. A building cools off faster at first and slows as it approaches the temperature of its surroundings. Thermal conductivity is the second factor in determining how fast a material heats or cools, that is, how easily heat can move through the material. For example, a metal spoon has a high thermal conductivity – the handle warms quickly, while a plastic or wooden spoon, with their low thermal conductivity, hardly warm at all.

2. Convection is the process where heat is transferred by the movement of fluids (liquids or gases). Warm air is less dense than cold air, causing natural convection as warm air rises and cool air sinks. Convection drives global air circulation and weather patterns. In a passive solar greenhouse, we make use of natural convection to regulate interior temperature without fans (using the so-called "chimney effect"). Forced convection happens when fans or breezes move air across surfaces, speeding heat transfer. Wind chill is a familiar example of this effect.

3. Thermal radiation is transfer of heat by electromagnetic waves. When radiation hits a surface, part of it is reflected and part of it is absorbed and converted to heat. Every object above absolute zero is constantly radiating to whatever it can “see” and absorbing the radiation aimed at it from its surroundings. The warmer object emits more energy to the cooler object than it emits back, so the net heat moves from warm to cool – the same direction as conduction and convection. When the temperatures equalize, the exchange becomes balanced and the system has reached thermal equilibrium.

The sun's energy travels 93 million miles through space via radiation, warming the Earth and, in turn, our greenhouses. Thermal radiation transfers heat from surface to surface without the need of any medium (solids, liquids or gasses). Other familiar examples of this type of heat transfer include campfires, radiant heaters, heat lamps, and wood stoves. When standing close to either, only the side "facing" the stove or fire is warmed, the side turned away does not experience any

warming. You might also observe that air temperature is not directly affected by the radiation from the stove or fire!

In a greenhouse, glazing materials transmit or reflect radiant energy depending on their properties and their angle to the sun. Surfaces that absorb radiation heat up, while those that reflect it stay cooler. Surface color and texture matter – dark, dull surfaces absorb and emit radiation more effectively than shiny, light-colored ones.

Thermal Conductors, Insulators, and Emissivity

A material's thermal conductivity describes how readily it transfers heat (heats or cools). Metals like copper and silver are excellent conductors. Air, wood, styrofoam are poor conductors and thus make effective insulators. Insulation slows heat loss, allowing a greenhouse to better retain its solar thermal energy.

A related concept is emissivity, or how well a surface emits radiant energy. This is determined in part by the material and color of its surface. A material that is a good absorber of radiant energy is also a good emitter of radiant energy. In other words, if it easily gets hot, it will also cool quickly and vice versa. A black-painted barrel absorbs heat easily and releases it quickly, while a shiny foil surface reflects most radiation.

Quantitatively, emissivity (ε) is the ratio of the thermal radiation from a surface to the radiation from an ideal black surface at the same temperature (the Stefan–Boltzmann law). The surface of a perfect black body (with an emissivity of 1) emits thermal radiation at the rate of approximately 448 watts per square meter (W/m^2) at a room temperature of 25°C (298°K; 77°F). Real objects have emissivities less than 1.0, and emit radiation at correspondingly lower rates (source: https://en.wikipedia.org/wiki/Emissivity, accessed June 1, 2026). The ratio varies from 0 to 1 for ordinary surfaces; Table VIII.1 shows the emissivity of some common materials.

Table VIII. Emissivity of different materials.

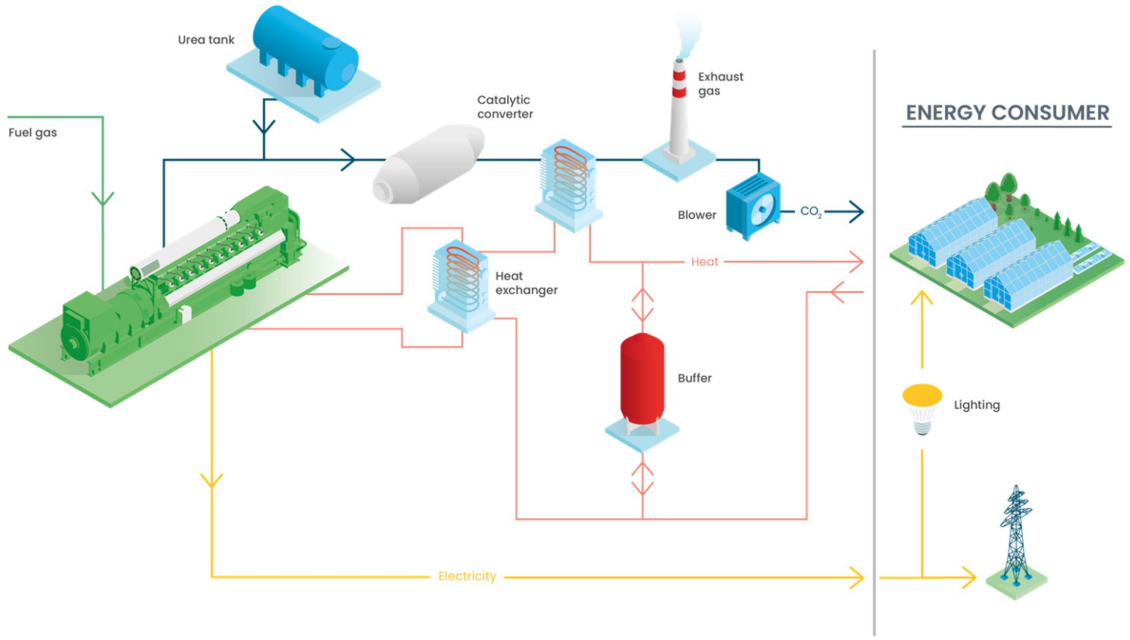
Material	Emissivity (ε)	Material	Emissivity (ε)
Brick	0.81-0.86	Plexiglass	0.86
Brick masonry	0.94	Polypropylene	0.97
Concrete, dry	0.95	Dry Soil	0.92
Firebrick	0.68	Frozen soil	0.93
Granite, natural surface	0.96	Saturated soil	0.95
Limestone, natural surface	0.96	Vegetation	0.92-0.96
Gravel	0.28	Water	0.95
Glass, smooth, uncoated	0.92	Snow	0.80
PVC	0.91-0.93	Ice	0.97
Acryilic, clear	0.94	Flat black oil paint	0.94

A crucial detail for PSG design is that the temperature *difference* is a major factor determining convection and conduction heat flow rates between objects and substances. However, the *radiative heat flow rate* is determined by the *temperature difference to the fourth power* (Temp diff x Temp diff x Temp diff x Temp diff). Doubling the temperature difference and the radiative heat loss goes up sixteen times! This is why a hot interior on a cold clear winter night loses so much heat through the glazing to the sky, and why a nighttime insulating curtain over the glazing is one of the best investments per dollar for a passive solar greenhouse.

Laws of Thermodynamics paraphrased

1. Energy cannot be created or destroyed. The energy entering a system must equal the energy leaving it, though it may change forms.
2. The quality of the energy is determined by its temperature or how much work it can do.
3. Energy degrades in quality as it is used. High-quality, concentrated energy (like electricity or gasoline) becomes lower-quality energy (waste heat) when converted. This explains why efficiency is so important.

Cogeneration is a process of using the waste heat generated by one task to do work that does not require as high of a quality of energy for successive tasks. Combined heat and power systems have very high efficiencies by using this principle. A system might burn a high-quality fuel to boil water (at over 212° F) to create steam to turn a turbine producing (very high-quality) electricity, then use the very hot water coming out of the turbine to heat (140°-180° F) the facility as well as heat water for domestic use (at 120° F)! So, the waste heat from one system provides the lower-level heat needed for the next system "down the thermal stream" to operate. In greenhouse operations, the CO_2 produced by burning natural gas or oil to heat the structure is also used to enhance carbon dioxide levels to 'fertilize' the crops produced in the structure.



Source: https://www.jenbacher.com/en/energy-solutions/industries/greenhouse/ , accessed July 3, 2026.

Specific Heat and Thermal Mass

Specific heat is used to measure how much heat a material can hold. It is the amount of energy required to raise the temperature of one unit (kilogram, pound) of a material by 1 degree. In formula form:

Heat Capacity	=	Specific Heat	x	Density
(kcal/m^3-^{0}C or Btu/ft^3-^{0}F)		(kcal/kg-^{0}C or Btu/lb-^{0}F)		(kg/m^3 or lb/ft^3)

The heat capacity of different materials is provided in Table VIII.1. Materials with high heat capacity, such as water, can store large amounts of energy without large temperature swings, making water an excellent thermal mass for greenhouses. Materials with low heat capacity are good insulators. This is particularly important when determining the type and amount of thermal mass and insulation to be used in a greenhouse as different materials heat and cool at different rates and amounts. We will discuss this in more detail in the following chapter on thermal mass.

Table VIII.1. Specific heat and heat capacity of different materials.

Material	**Specific Heat** Btu/lb-^{0}F	**Density** lb/ft^3	**Heat Capacity** Btu/ft^3-^{0}F
Air	0.24	0.075	0.018
Water	1	62.32	62.32
Sand	0.191	94.6	18.1
Brick	0.201	123	24.7
Concrete	0.156	144	22.5
Steel	0.12	489	58.7
Hardwoods	0.45-0.65	23-50	10.4-32.5
Softwoods	0.6	27	16.2
Wool fabric	0.32	6.9	2.2
Expanded polyurethane	0.38	1.5	0.42
Polycarbonate	0.28-0.299	74.9	21-22.4
Glass wool (bat insulation)	0.157	3.25	0.51

Changes of State and Phase

When we talk about what phase (or state) a substance is in we are talking about whether it's a solid, liquid or gas. When a substance changes its phase/state (from solid to liquid to gas, or vice-versa), it absorbs or releases large amounts of energy without changing temperature. Imagine a glass of ice water; both the ice and liquid remain at 0°C until all the ice has melted - only then does the liquid water start to warm. To melt ice to liquid water at 0°C requires 80 kcal per kg at sea level; bringing 0^0 C water to boiling point (100^0 C) requires 100 kcal/kg; then

boiling it all to steam of 100° C requires 540 kcal/kg (Figure VIII.1). So, it takes 6.75 times more energy for boiling water to steam than to melt ice into liquid water.

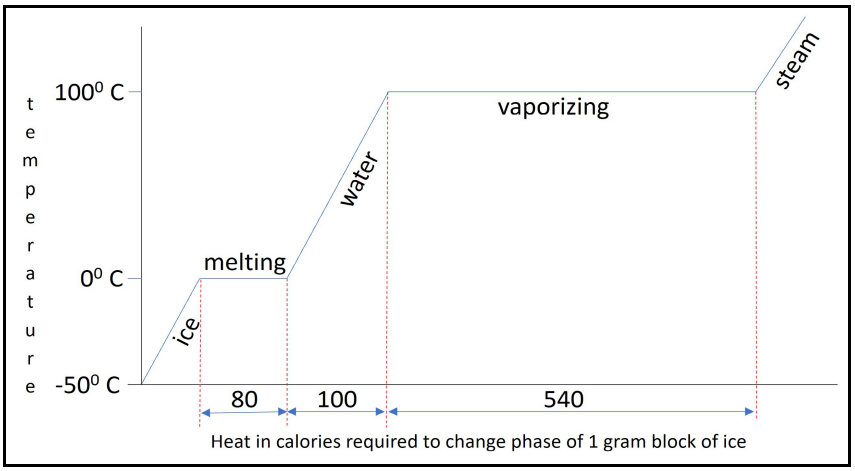
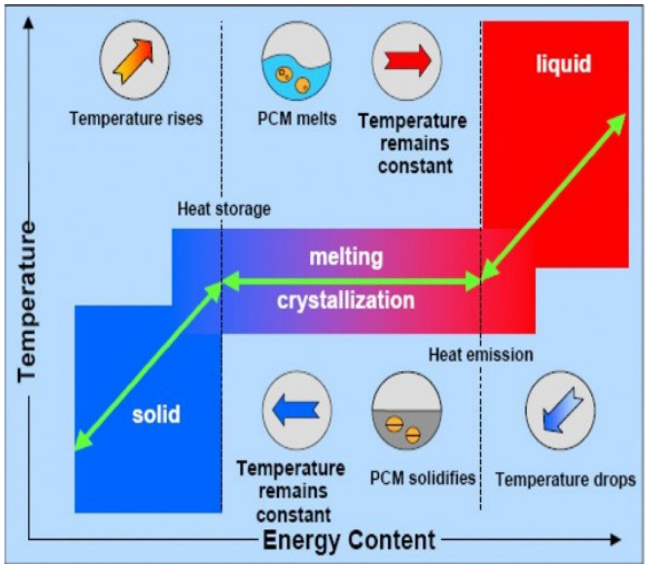


Figure VIII.1. Amount of heat (Kcal) for 1 kilogram block of ice to change its phase from ice to liquid water to steam.

This property of matter allows us to develop what we call Phase Change Materials (PCM) which use the idea that it takes a lot more energy to melt or freeze a material than it takes to change its temperature (we might say water is a "temperature change material"). Two of PCM's primary purposes as presently used are to help cool buildings on hot days and keep foods, chemicals, etc. at a specific constant (cool) temperature. By absorbing or releasing heat at specific preset temperatures (as shown in the diagram to the right), PCMs can stabilize greenhouse conditions in a narrow range without taking up as much space as water barrels. This principle makes Phase Change Materials (PCM) potentially powerful tools.



Why This Matters for PSGs

An understanding of energy, heat, and temperature explains why passive solar greenhouses work so effectively. Proper use of insulation, glazing, and thermal mass captures solar energy, slows heat loss, and keeps conditions stable. Conduction, convection, and radiation all play roles in moving heat around the greenhouse. The high specific heat of water and the stabilizing effects of PCM make them ideal for greenhouse applications. And the natural laws of energy remind us: to design well, we must work with these principles, not against them.

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Further Reading

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