



STUDY GUIDE - PRINCIPLES OF ENERGY

Learning Objective

- Be familiar with energy principles underlying:
 - comfort,
 - heat flow, and
 - electricity use

Energy: a measurable quantity of heat, work, or light.

- Potential Energy is *stored*.
- Kinetic Energy is *transitional*.

Two Major Approaches to the Wise

- Energy Efficiency
- Energy Conservation

Categories of Residential Inefficiency

- Heating
- Heat Losses
- Air Leakage
- Water Heating
- Cooling
- Heat Gains
- Distribution Systems
- Appliances/Lighting
- Residential Behavior

Seasonal & Base-load Consumption

- Homes normally consume 40%-50% of energy for heating/cooling (seasonal)
- Base-load will remain fairly stable - based on plug loads, including:
 - vampire loads
 - consumer habits

Measurements for Energy Consumption- IMPORTANT!

- Natural gas: measured in:
 - hundred cubic feet (1 **ccf**)
 - thousand cubic feet (1 **mcf**), or a therm
 - **1 ccf** = a **therm** which = approximately 100,000 **BTUs**
 - **1 mcf** = a million BTUs (MMBTU)
 - **1 cubic foot (1 cf) = 1000 BTUs**

- Electrical energy: measured in **kW-hours**.
 - **1 Kilowatt Hour = 3412.14 BTUs**
 - 1 million BTUs (1 MMBTU) = 293 Kilowatt Hours ($1 \text{ BTU} = 0.00293 \text{ KWH}$)
 - Costs of different fuels (gas, oil, propane, electricity) are commonly compared in MMBTUs
 - <http://www.calculateme.com/Energy/KilowattHours/ToBTUs.htm>

Life-Cycle Costing

- Payback Period
- Annual Return
- Life-Cycle Cost
- Compare the life-cycle cost of taking action with life-cycle cost of not taking action.
- If the cost of action is less over time than inaction, take action.

First Law of Thermal Dynamics

- Energy is Neither Created or Destroyed
- It Only Moves from Here to There
- And/or Changes Form

Second Law of Thermal Dynamics

- Heat Moves from High Temperature Regions to Low Temperature Regions
- Heat Always Travels from Hot to Cold
- All Things in Nature Go from Order to Disorder

Temperature and Heat

- Temperature is a measure of how fast the molecules in a substance are moving or vibrating
- Heat flows because of a difference in temperature between two areas (ΔT)
- The process of cooling involves removing energy from a system

BTU: British Thermal Unit

- The amount of heat required to raise the temperature of 1 lb. of water 1 degree Fahrenheit
- **$q(\text{BTU}) = U \times A \times \Delta T$**
- **Sample problem:** What is the heat transfer of a ceiling having the measurements of 30' x 60' ceiling with R-38 insulation, if the inside temperature is 72° and outside temperature is 25°?
 - **$U = 1/R$ therefore: $1/38 = 0.026U$**
 - **Area = 30 x 60 or 1800 sq/ft**
 - **$\Delta T = 72-25$ or 47°**
 - **$q(\text{BTU}) = 0.026 \times 1800 \times 47$**
 - **$q(\text{BTU}) = 2,200 \text{ btu/hr}$**

Latent Heat

Unexpected or hidden heat, released or absorbed as a substance changes phases or states. Two latent heats are typically described: latent heat of fusion (melting), and latent heat of vaporization (boiling). The names describe the direction of heat flow from one phase to the next: solid → liquid → gas.

Supplemental explanation: The change is endothermic (absorbing energy) when the change is from solid to liquid to gas. It is exothermic (releasing energy) when it is in the opposite direction. For example, in the atmosphere, when a molecule of water evaporates from the surface of any body of water, *energy* is transported by the water molecule into a lower temperature air parcel that contains more water vapor than its surroundings.

Since energy is needed to overcome the molecular forces of attraction between water particles, the process of transition from water to water vapor requires the input of energy causing a drop in temperature in its surroundings. If the water vapor condenses back to a liquid or solid phase onto a surface, the latent energy absorbed during evaporation is released as sensible heat onto the surface. The large value of the enthalpy of condensation of water vapor is the reason that steam is far more effective as a heating medium than boiling water.

Sensible Heat

The heat required to change the temperature of a substance is called as sensible heat. Add 150 BTUs to a pound of water and its temperature increases 150°F to the temperature of 200°F. This sensible relationship ends at 212°F, water's boiling point.

Supplemental Explanation: Sensible heat is potential energy in the form of thermal energy or heat. The thermal body must have a temperature higher than its surroundings (see also latent heat). The thermal energy can be transported via conduction, convection, radiation or by a combination thereof. The quantity or magnitude of sensible heat is the product of the body's mass, its specific heat capacity and its temperature above a reference temperature. In many cases the reference temperature is inferred from common knowledge, i.e. "room temperature".

Energy vs. Power

Power is energy divided by time. It is the rate at which work is done or heat is released. In physics, **power** (symbol: P) is the rate at which work is performed or energy is transmitted, or the amount of energy required or expended for a given unit of time. As a rate of change of work done or the energy of a subsystem, power is: where P is power, W is work and t is time.

The **average power** is the average amount of work done or energy transferred per unit time. The **instantaneous power** is then the limiting value of the average power as the time interval Δt approaches zero.

If a 100,000 BTU/hour furnace runs for 10 hours, it converted, 1 million BTUs of the fuel's potential energy to heat.

Calculating POWER

The heat content of one cord of hardwood is 20 million BTUs. If a woodstove burned a cord of wood in 200 hours, its POWER would be calculated by dividing the ENERGY (the 20 million BTUs in a cord of wood) by the TIME (the 200 hours it took to burn).

- a. $20 \text{ million BTUs} \div 200 \text{ hrs} = 100,000 \text{ BTUs/hour of POWER}$

Types of Heat Flow

Heat travels from areas of high temperature to areas of low temperature in three ways:

- Conduction
- Convection
- Radiation

Conduction – heat transfer through solid materials or objects touching

The transfer of heat by **direct contact** of particles of matter

Conduction is greater in solids, where atoms are in constant contact

- Metals (e.g. copper) are usually the best conductors of thermal energy
- As density decreases so does conduction. Therefore, fluids (and especially gases) are less conductive
- A heat pipe is a passive device that is constructed in such a way that it acts as though it has extremely high thermal conductivity.

Convection – always involves a fluid (air, water, gas)

- The movement of molecules within fluids (i.e. liquids, gases including air)
- Heated area has reduced density causing it to rise; lower density areas descend
- Heat causes a be carried passively by fluid motion which would occur anyway without the heating process (a he change in density

Supplemental Explanation: A common use of the term convection leaves out the word "heat" but nevertheless refers to heat convection: that is, the case in which heat is the entity of interest being carried and dispersed.

In one of two major types of heat convection, the heat may be carried passively by fluid motion which would occur anyway without the heating process (a change in density) at transfer process termed loosely as "forced convection").

In the *other* major type of heat convection, heating itself may *cause* the fluid motion (via expansion and buoyancy force), while at the same time also causing heat to be transported by this motion of the fluid (a process known loosely as natural convection, or "free convection"). In the latter case, the problem of heat transport (and related transport of other substances in the fluid due to it) is generally more complicated. Both forced and natural types of heat convection may occur together.

Convection Loops

- Heat added to one part of a fluid causes molecules to move faster.
- The heated area has reduced density causing it to rise; lower density areas descend.
- Heat causes a change in density.

Radiation

- Heat transferred from one object to another **through space**
- **Requires line of sight**

Radiation: Seasonal Changes – The sun's changing path across the sky

- **4 Types of Radiation Behavior**
 - Emission
 - Reflection
 - Absorption
 - Transmission

Thermal radiation: electromagnetic radiation **emitted** from the surface of an object due to the object's temperature.

Why Do We Insulate?

- The un-insulated wall transmits energy through its air space by both convection and radiation.
- In an insulated wall, heat must conduct through tiny air pockets trapped by the insulation – a slower process

Heating Degree Day (HDD)

- A unit of measurement to describe how long the temperature is below 65°F during each day, month or year
- Take the average outdoor temperature for any day and subtract it from 65°F;
- Example: High of 30°F, low of 0°F = average of 15°F. **65°F - 15°F = 50 HDDs.**
- Example: The average temperature for a given day is 55°F. Since this value is 10 degrees lower than the reference point of 65°F then one would say this is a *ten degree-day*.
- Anchorage, Alaska has 10,864 HDD/year

Miami Beach has 141 HDD/year Cooling-Degree Day

A unit for measuring the air temperature difference between the outdoors and 78°F over the hot summer season. Cooling-degree days measure the intensity of the summer climate.

Supplemental explanation: Heating degree day (HDD) and cooling degree day (CDD) are quantitative indices designed to reflect the demand for energy needed to heat or cool a home or business. They're derived from daily temperature observations, and the heating (or

cooling) requirements for a given structure at a specific location are considered to be directly proportional to the number of heating degree days at that location.

The number of heating degrees in a day is defined as the difference between a reference value of 65°F (18°C) and the average outside temperature for that day. The value of 65°F is taken as a reference point because experience shows that if the outside temperature is this value then no heating or cooling is normally required. Occupants and equipment within a building usually add enough heat to bring the temperature up to a more comfortable level.

Four Comfort Factors:

- Air temp
- Relative Humidity
- “Mean” radiant temp
- Moving air

Humidity

- Air temperature & amount of water vapor in the air determine how much heat the air contains
- The higher the humidity at a given temperature, the more heat the air holds.

Relative humidity (RH)

- The % of moisture absorbed in the air compared to the maximum amount possible;
- Completely saturated air has an RH of 100%
- The ratio of the partial pressure of water vapor in a parcel of air to the saturated pressure of water vapor at a prescribed temperature

NOTE: A sling psychrometer is used for measuring relative humidity.

Indoor Relative Humidity

- **Warmer air can hold more moisture than colder air**
- **Most common range for comfort level in a home is 30%-50% RH**
- Indoor RH lower than 60% in the summer promotes comfort
- Indoor RH in winter should be less than 40% to prevent indoor condensation on cooler surfaces
- Example: sweating windows means too much moisture in the house; is there a vent-less fireplace?

Dew Point:

- The warmest temperature of an object in an environment where water condensation from surrounding air would form on that object
- The temperature at which water vapor will become liquid

Possible Areas of Condensation in a Home

- Windows
- Behind furniture on exterior walls
- On un-insulated ceiling areas
- On supply registers when furnace is off and an unvented fireplace is being used

Byproducts of Combustion

- Water
- Carbon Dioxide
- Carbon Monoxide

Summary

- Baseload - average the lowest 3 months when neither the heating nor AC is in use
- Heat moves from warmer to cooler
- Heat moves in 3 ways:
 - Conduction
 - Convection
 - Radiation
- Balance between operative temperature & mean radiant temperature improves comfort
- Dewpoint - warmest temperature of an object where water condenses from surrounding air

Principles of Energy - Practice Questions

Which of the following is not among the four environmental factors that affect human comfort in the indoor environment?

- a. The temperature of the air
- b. The Delta T
- c. The relative humidity
- d. The mean radiant temperature

Three million Btus is equal to how many kWh?

- a. 293
- b. 10,238
- c. 879
- d. 50,000



What range of room relative humidity is considered ideal for home occupants?

- a. 10%-30%
- b. 30%-50%
- c. 40%-60%
- d. 50%-70%

When does condensation occur?

- a. When the temperature goes below the dew point
- b. When the relative humidity of the air reaches 100%
- c. When the temperature of a surface is less than the dew point
- d. When the relative humidity of the outside air is above 60%

One kWh equals

- a. 3413 Btu/hr.
- b. 0.000293 Btu
- c. 3412 Btu
- d. 1 Therm

Comfort is not a function of which of the following:

- a. air temperature
- b. mean radiant temperature
- c. relative humidity
- d. exfiltration

What is the heat transfer for a ceiling having measurements of 30' x 60' with R-38 if the inside temperature is 72 and the outside temperature is 25?

- a. 22,000 btu/hr
- b. 2,200 btu/hr
- c. 1455 btu/hr
- d. 3,214,800 btu/hr

Without changing the grains of water in the air, if the air is heated, the relative humidity will:

- a. increase
- b. decrease
- c. stay the same
- d. cause condensation

Convection is best exemplified by:

- a. Warm air exfiltrating into the attic from the house.
- b. Heat traveling through space.
- c. Diffusion and perm rating.
- d. Condensation on iced tea glass.



In what climate zone would a house be found that has 10,600 heating degree days and receives approximately 25 to 30 inches of rain a year?

- a. Cold
- b. Mixed humid
- c. Hot humid
- d. Hot dry

What is a common unit used when comparing fuels such as oil, gas and LP?

- a. mpg
- b. mmbtu
- c. gallons
- d. kwh

Approximately how many cubic feet of natural gas would be required to produce 275,000 Btus?

- a. 3.412
- b. 0.293
- c. 275
- d. 3412