Efficiency

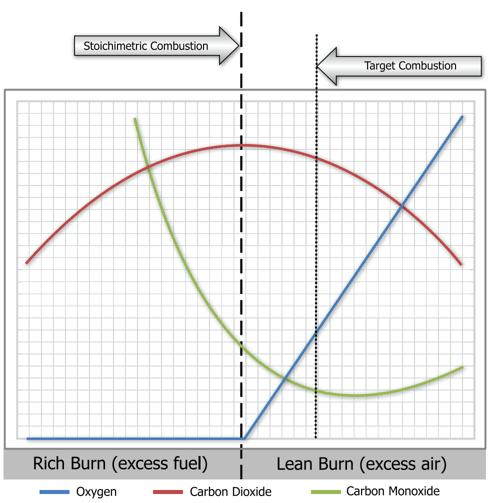
Heating with infrared technology is an excellent method to reduce energy costs. However, the fact that infrared technology is fundamentally different than traditional means of heating requires special attention when evaluating an infrared appliance for its efficiency.

Efficiency = What you get out ÷ What you put in

There are several different efficiencies that can be utilized when comparing infrared heaters. Understanding how these efficiencies are derived and how they apply will aid in selecting the proper unit for an application.

Combustion Efficiency

Combustion efficiency is a measure of how complete an appliance converts the supplied fuel into heat energy. 100% combustion efficiency, or stoichiometric combustion, is achieved when the exact amount of oxygen required to burn a specific amount of fuel is supplied to the reaction; no more, no less. This is also commonly referred to as perfect combustion.



Stoichiometric Combustion

At standard temperature and pressure, there are approximately 761,300,000,000,000,000,000,000 molecules in one cubic foot of gas.

Every molecule would have to come into contact with oxygen molecules at exactly the right time and place for 100% combustion of this gas to occur.

Stoichiometric equation for natural gas: $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

In practice, "perfect combustion" is nearly impossible to achieve. In fact, this is unfavorable in most heating appliances because the slightest change in the environment could easily starve the flame of oxygen, resulting in high levels of noxious gasses. Therefore, most heating appliance manufacturers adjust the air-to-fuel ratio to allow for a small amount of excess air. This will minimize the pollutants created, and still maximize the efficiency. The graph above depicts the combustion process, and demonstrates the relationship between its products when changing the amount of air supplied.

The Four Efficiencies of Infrared

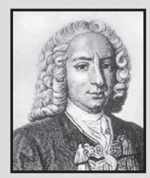
Combustion Efficiency: A measure of how complete an appliance converts fuel into heat energy.

Thermal Efficiency: A measure of all energy (conductive, convective and radiant) captured by the heater.

Radiant Efficiency: A measure of all radiant energy leaving the heater.

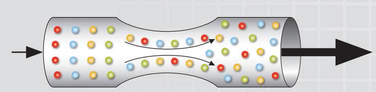
Pattern Efficiency: A measure of how effectively an appliance delivers radiant energy into a heat pattern.

Bernoulli's Principle



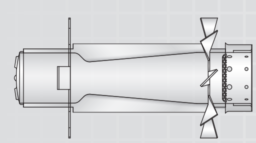
Daniel Bernoulli [1700–1782]

States that when there is a decrease in pressure there must be an increase in velocity at the same rate that the pressure was decreased. This principle is most commonly attributed to the theory of lift, as generated by an airfoil, but it also plays a role in burner design.

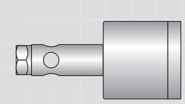


Increased Velocity

Well designed burners will utilize a venturi, or a tube with a narrowed passage, for the purpose of increasing velocity through the tube. This results in better aeration, better mixing, better flame stability and better combustion efficiency.



Venturi Burner Design



Non-Venturi Burner Design

Your Next Paycheck...

When cashing your next paycheck, think of thermal efficiency. Your gross pay (energy in) reflects what you earned. Your net pay (energy out) reflects what you take home.

The Infrared Industry

Currently the infrared industry and the American National Standards Institute (ANSI) use thermal efficiency as the sole method to measure the efficiency of the appliance.

While this measure of efficiency may be suitable for appliances such as unit heaters or boilers, it does not depict the total efficiency of infrared heaters.

As a result, this current efficiency standard has allowed some manufacturers to produce a cheaper, lesser quality heater with low radiant output exchangers and less reflective reflectors.

Various industry standard committees recognize this problem and are working to develop a radiant efficiency standard to accurately measure the efficiency of infrared heaters.

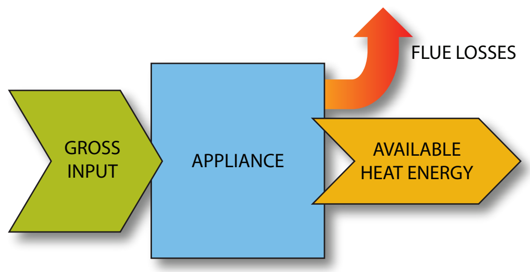
Considering Electric?

While often promoted as being 100% efficient, remember that most electric heaters are powered by upstream, gas-fired power generators subject to significant energy transmission losses.

Thermal Efficiency

Thermal efficiency is the measure of all energy — conductive, convective and radiant — captured by the heater. Thermal efficiency is currently the industry standard used to measure the efficiency of an infrared heater in the United States of America and Canada.

Thermal efficiency is a measure of the total heat energy captured by an appliance which is available for useful output. The Sankey diagram below is a good visual depiction of this process.



Sankey Diagram

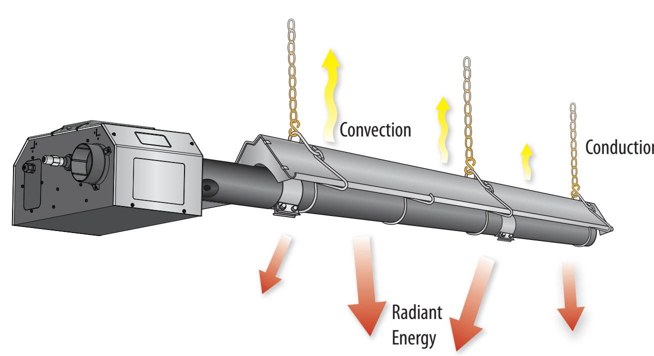
A specific type of flow diagram, in which the width of the arrows is shown proportionally to the flow quantity. They are typically used to visualize energy or material transfers between processes.

The gross input is the total amount of heat energy supplied to the appliance through the combustion process. The majority of that energy is captured within the appliance, but some escapes through the flue, which is counted as a thermal loss. Once the available heat energy is captured within the appliance, it can be emitted in three different forms; convection, conduction, and radiation. Every infrared heater is required to pass a minimum thermal efficiency rating. A well designed infrared heater maximizes the radiant output while minimizing the convection and conduction thermal movements.

Oftentimes, infrared heating solutions are sold on thermal efficiency claims alone, and generally claims that cannot be fully attained. The additional cost to achieve optimal thermal efficiency far outweighs any theoretical payback when utilizing an infrared appliance.

Thermal Energy of an Infrared Heater

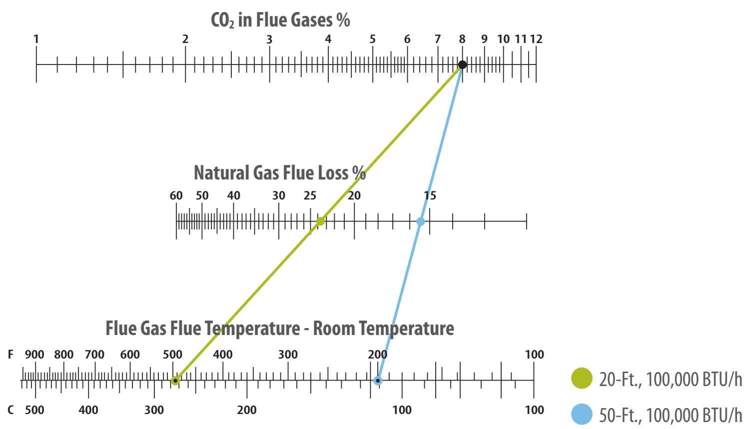
The diagram below demonstrates the three forms of heat energy leaving a tube style heater. Note the convective energy in yellow, the radiant energy in red and the conductive energy in orange.



The Testing Process

ANSI Z83.20 is the recognized standard governing the certification of an infrared tube heater. The Standard is over 140 pages in length and details all of the required tests and regulatory procedures for a gas-fired low intensity infrared heater.

The diagram shown below highlights the key variables in testing for the rated thermal efficiency of the appliance. As you can see, the efficiency rating is a measurement of both the CO_2 (combustion efficiency) and the stack temperature (flue loss).

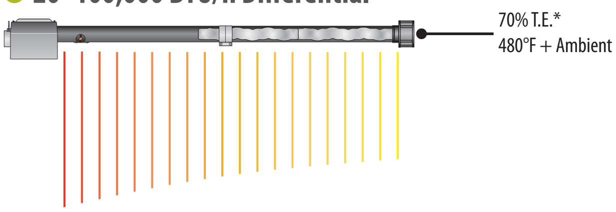


Thermal Efficiency Rating Diagram

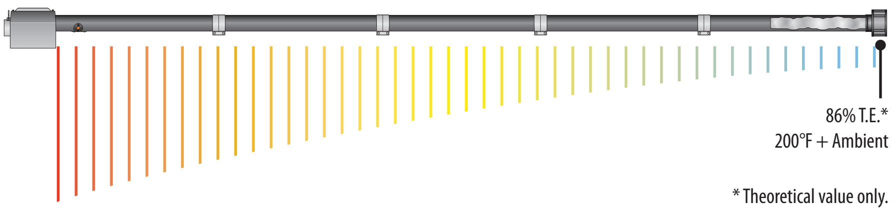
Tube Heaters are Unique

Two heaters with the same combustion efficiency (CO_2) can have very different thermal efficiencies by the addition of radiant pipe to the appliance. This must be done with careful consideration as a longer infrared tube heater will have pronounced temperature differentials and emit very little heat towards the exhaust end. Very often, the best performing heater may fall in the middle of the range of available lengths for a particular BTU model. This model is often representative of both good thermal and radiant performance characteristics.

20'-100,000 BTU/h Differential



50'-100,000 BTU/h Differential



* Theoretical value only.

Certification Guidelines

The Construction and Operation Standard for Low Intensity Heaters (ANSI Z83.20) dictates a maximum allowable exhaust temperature of 480°F plus the ambient temperature, a minimum 70% thermal efficiency value, and no more than 400ppm carbon monoxide (CO) in an air free sample.

Exhaust temperature above 480°F results in an excessive loss of usable heat and could potentially compromise vent ducts or terminations. Temperatures below 200°F will yield poor radiant performance and are subject to condensation.

Consider This

Oftentimes, vacuum systems are promoted as being more efficient than the unitary push tube. Surprisingly, this is only achieved when the system is installed at maximum allowable lengths and is allowed to condense.

Another often overlooked factor between a unitary push tube and vacuum system is the vacuum pump's high electrical consumption. This should be considered when calculating overall system efficiencies.

For additional information on vacuum system efficiencies, please see pages 7-2 & 7-3.

Some History

Radiation formulas such as the Stefan-Boltzmann Law have been in existence since the 1800's. These formulas along with other pertinent radiant data are found in the ASHRAE Fundamentals Handbook.

Developing an accurate radiant efficiency standard has been sought after for many years with little success. Various infrared manufacturers have funded campaigns for the development of a radiant efficiency standard to no avail.

Presently, the domestic infrared industry conducts certification testing by using only a thermal efficiency method. Radiant effectiveness is conveyed by using known physics and laws which help to distinguish a product and its performance.

Certification of Europe

European Standard BS EN 416-2 is the leading authority in the quantification of rational use of radiant energy. Infrared products bearing the CE mark will have been tested to this Standard.

Appliances tested to the European Standard must meet a minimum thermal and radiant efficiency value and are rated accordingly. This is a more objective method to properly evaluate the total performance of the appliance.

Radiant Efficiency

Radiant efficiency is a measure of how much thermal energy is emitted as radiant heat energy. This form of thermal transfer is fundamentally different from conduction or convection in that it does not require an intermediary device to transfer the heat energy. This greatly reduces the transmission losses, because it sends the heat directly to the intended load. Thus, heating with radiant energy is a more effective and efficient means of heating over traditional forced warm air systems.

Stefan-Boltzmann Law

The theoretical radiant output of a surface can be calculated by utilizing the Stefan-Boltzmann law. According to this Law, a small increase in the temperature of a radiating body results in a large amount of additional radiation being emitted.

The following equation describes this law mathematically:

$$w = A\epsilon\sigma T^4$$, where

- w = Total radiant output
- A = Area
- ϵ = Emissive Value
- σ = Stefan-Boltzmann constant
- T = Absolute temperature

For example, an exchanger tube at a temperature of 1200°F has nearly twice as much radiant output as a similar exchanger tube at 900°F.

When comparing two identical tube heaters (for instance, a 40-ft., 150,000 BTU/h model) with different surface temperatures, it is simple to see how drastically the surface temperature effects the radiant output (shown below).

Heater A

900°F

A = $153.2m^2$
ϵ = 0.90
σ = $5.6704 \times 10^{-8} Js^{-1}m^{-2}K^{-4}$
T = 755°K

Heater B

1200°F

A = $153.2m^2$
ϵ = 0.90
σ = $5.6704 \times 10^{-8} Js^{-1}m^{-2}K^{-4}$
T = 922°K

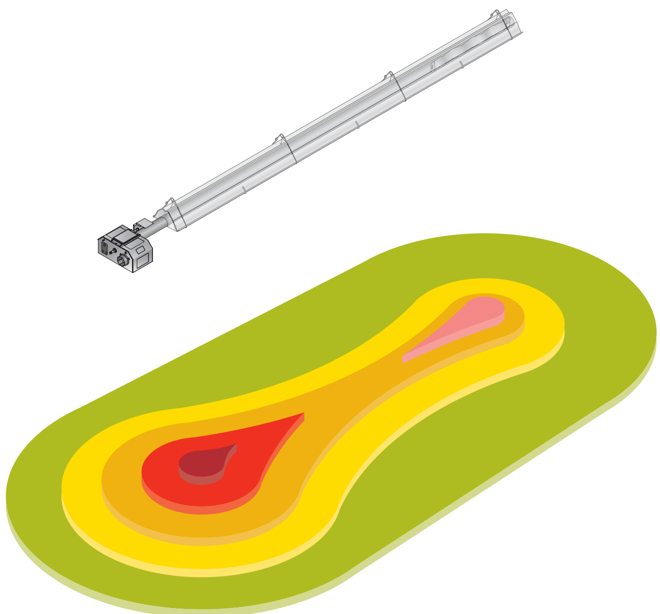
To calculate the percent reduction in radiant output, simply divide Heater A by Heater B, as shown:

$$\frac{\textbf{Heater A Output:}\ [(153.2)(.90)(5.6704 \times 10^{-8})(755)^4]}{\textbf{Heater B Output:}\ [(153.2)(.90)(5.6704 \times 10^{-8})(922)^4]} = .45 \text{ or a 55\% reduction of radiant output.}$$

Pattern Efficiency

Pattern efficiency is the measure of how effectively an appliance directs radiant heat energy into a usable heat pattern. This pattern, coupled with the proper application of the product, influences the system's total effectiveness.

Mounting height, reflector design, material, and application all determine whether or not the desired pattern will be prevalent. This pattern is often measured in BTU/h per square foot; also known as Effective Radiant Flux.



This step in the 'gas-to-useful heat' process is critical because it is a good indicator of the distribution of heat energy. Even the most efficient radiant heaters may prove ineffective if applied improperly, resulting in poor pattern efficiency.

What is Radiant Flux Density?

Radiant flux density is the power of electromagnetic radiation falling on or emanating from a body, measured as watts per square meter.

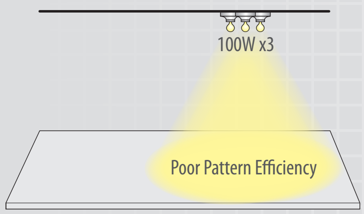
Flux has a primary mathematical definition in terms of a surface integral which uses the vectors that represent the force which is causing the flux being studied:

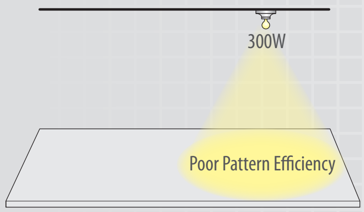
$$Flux = \iint_S \vec{F} \cdot \hat{n} dS = \iint_R \vec{F} \cdot < -\frac{\partial z}{\partial x}, -\frac{\partial z}{\partial y}, 1 > dxdy$$

Did you Know?

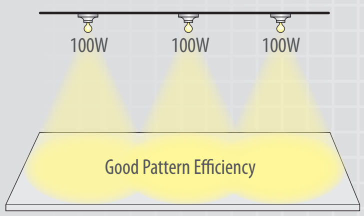
Similar to lighting a space, the goal of infrared heating is to obtain highly efficient heat by directing the infrared energy in a specific pattern.

Poor Pattern

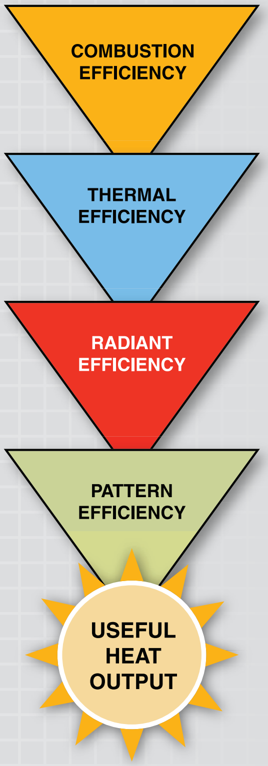




Ideal Pattern



The effective application of the pattern to the thermal load influences the system's total effectiveness.



Two Stage Operation

Two stage infrared heaters operate in a high (100%) or a low (65%) output mode according to demand. This technology will result in additional fuel savings and bottom line energy savings. To learn more about two stage operation, please see page 10-2.

The Bottom Line

Recognize the difference between system efficiency and device efficiency. Infrared systems have been proven to outperform most 'device efficient' appliances.

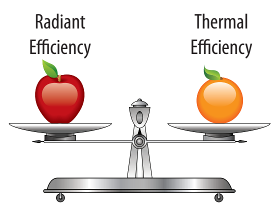
Accordingly, the overall operating efficiency of an infrared system should be the most important criterion when selecting a heating solution.

Let's Review

- **Combustion Efficiency** is important as it is a direct indicator of the performance of the burner operating within the appliance.
- **Thermal Efficiency** is the recognized North American testing method and is important as it is a measurement of all energy leaving the appliance.
- **Radiant Efficiency** is of significant importance when discussing the performance of a radiant tube heater.
- **Pattern Efficiency** attempts to quantify the flux density of coverage and pattern from the heater.

Collectively all of these known efficiencies should be considered when weighing the overall performance of the infrared heater.

European Standards



The European Test Standard necessary for CE Certification recognizes the importance of rational use of energy when weighing the overall efficiency of an appliance. This method will most likely be adapted in the North American marketplace.

Conclusion

- Many factors contribute to the performance of an infrared system; it is unwise to select a system based on a single criterion.
- Radiant efficiency and thermal efficiency should be given equal consideration.
- The simple addition of excess radiant pipe to an infrared heater can raise the thermal efficiency. However, this may not be productive or yield favorable performance results.
- Definitive radiant claims within the North American market should be viewed with skepticism as no recognized test method currently exists to substantiate such claims.
- A short length high BTU tube heater will display higher radiant and lesser thermal efficiency ratings. On the other hand, a long length low BTU tube heater will display higher thermal and lesser radiant efficiency ratings. Choose your models carefully.