Houses need to “breathe,” just like most living creatures. This is called ventilation and is crucial in the attic and the under-eave soffits (see red arrows below).

The EnergyStar page provided by the US government gives the following attic ventilation guidelines.

**Natural Attic Ventilation**

At first it may seem odd to add insulation for warmth and then purposely allow cold air to enter the attic through vents, but this combination is the key to a durable and energy-efficient home. Here’s why: in the winter, allowing a natural flow of outdoor air to ventilate the attic helps keep it cold, which reduces the potential for ice damming (snow that melts off a roof from an attic that is too warm and then re-freezes at the gutters, causing an ice dam that can damage the roof). Proper insulation and air sealing also keeps attics cold in winter by blocking the entry of heat and moist air from below. In the summer, natural air flow in a well-vented attic moves super-heated air out of the attic, protecting roof shingles and removing moisture. The insulation will resist heat transfer into the house.

https://www.energystar.gov/index.cfm?c=diy.diy_attic_ventilation
Furthermore, from the FHA

The U.S. FHA (Federal Housing Administration) recommends a minimum of at least 1 square foot of attic ventilation (both intake and exhaust) for every 300 square feet of attic space.

EFD:

**ASSUMPTIONS:** Air is an ideal gas, steady state, steady flow, 1-D uniform flow, uniform state

**BASIC EQUATIONS:** \( PV = mRT \)

**SOLUTION:**

Now consider an attic that is 25 feet wide and 15 feet long. **What is the recommended ventilation area if the FHA guideline is followed?** **What if the FHA guideline is doubled?**

**Report your answer in ft\(^2\).**

Attic space = 25’x15’ = 375 ft\(^2\)

\[
375\text{ft}^2\text{attic space} \times \frac{1\text{ft}^2\text{attic ventilation}}{300\text{ ft}^2\text{attic space}} = 1.25\text{ ft}^2\text{ attic ventilation}
\]

If you double the requirement:

\[
375\text{ft}^2\text{attic space} \times \frac{2\text{ ft}^2\text{ attic ventilation}}{300\text{ ft}^2\text{attic space}} = 2.5\text{ ft}^2\text{ attic ventilation}
\]

You purchase a ridge vent to install on your 14 foot long roof ridge. It provides 18 in\(^2\) (http://www.gaf.com/Roofing/Residential/Products/Roof_Vents/Cobra_Rigid_Vent_3) of
ventilation per lineal foot of vent. **Will this be enough to meet FHA guidelines?**

\[
14 \text{ ft lineal vent} \times \frac{18\text{in}^2 \text{ attic ventilation}}{1 \text{ ft lineal vent}} \times \frac{1\text{ft}^2 \text{ attic ventilation}}{144 \text{ in}^2 \text{ attic ventilation}} = 1.75 \text{ft}^2 \text{ attic ventilation}
\]

Yes, this meets guidelines. 1.75 ft\(^2\) of attic ventilation is greater than the requirement of 1.25 ft\(^2\) of attic ventilation.

You also need to provide soffit vents. You purchase soffits that provide 5 in\(^2\) of ventilation are per lineal foot. You have 15 lineal feet of soffit on either side of the attic. **Will you have enough ventilation area to meet the FHA recommendation?**

\[
2 \text{ sides of the attic} \times 15 \text{ ft lineal soffit vent} \times \frac{5\text{in}^2 \text{ attic vent}}{1 \text{ ft lineal soffit vent}} \times \frac{1\text{ft}^2 \text{ attic ventilation}}{144 \text{ in}^2 \text{ attic ventilation}} = 1.04 \text{ft}^2 \text{ attic ventilation}
\]

No, this does not meet the guideline of 1.25 ft\(^2\) of attic ventilation.

The outside temperature and pressure are 31.8 F and 30.38 in Hg, and the air speed through the ventilation areas (soffit and ridge) is 2.2 ft/s. **What is the air mass flow rate through the attic?** Transform ft\(^2\) and in\(^2\) to m\(^2\), ft/s to m/s, and find the air density in kg/m\(^3\).

Report your mass flow rate in kg/s.

The outside air flows into the soffit vents and out the ridge vents. They give us the temperature and pressure of the outside air so we use the soffit vent conditions.

English to SI

\[
\text{Area of soffit vents} = 1.04 \text{ ft}^2 \times \frac{(1^2) \text{m}^2}{(3.28^2) \text{ ft}^2} = 0.0967 \text{ m}^2
\]

\[
\text{Velocity} = 2.2 \text{ ft/s} \times \frac{1 \text{ m/s}}{3.28 \text{ ft}} = 0.671 \text{ m/s}
\]

\[
T = (31.8 \text{ } F + 460) \text{R} = 491.8 \text{R} = \left(\frac{491.8 \text{R}}{1.8}\right) \text{K} = 273 \text{ K}
\]

\[
P = 30.38 \text{ inHg} \times \frac{3386.39 \text{ Pa}}{1 \text{ inHg}} \times \frac{\text{ kPa}}{1000 \text{ Pa}} = 102.9 \text{ kPa}
\]

\[
\rho = \frac{P (MW)}{R_u T} = \frac{(102.9 \text{ kPa})(29 \text{ kg/kmol})}{8.314 \frac{\text{kJ}}{\text{kmol} - K}(273 \text{ K})} = 1.31 \text{ kg/m}^3
\]

Remember! We can only use \(m_{\text{in}} = \rho VA\) if we assume that the flow is 1-D, uniform flow, uniform state, and steady flow.
\[ m_{in} = \rho VA = 1.31 \frac{kg}{m^3} \times 0.671 \frac{m}{s} \times 0.0967 \, m^2 = 0.085 \frac{kg}{s} \]
Residential fireplaces in the US typically have flues that are 21.5 x 33 cm. For a typical wood fire the incoming air temperature is 25°C while the hot air going up the chimney is at 400°C. The hot air velocity is computed using

\[ V = C \sqrt{2 g H \left( \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}} \right)} \]

where \( C = 0.65, g = 9.8 \text{ m/s}^2 \), \( H \) is the chimney height (taken to be 5 m in this case), and \( T_{\text{cold}} \) and \( T_{\text{hot}} \) self-explanatory. **What is the air velocity up the flue?** Report your answer in m/s.

**Compute the heat transfer rate from the fire to the air.** Report your answer in kW.

**EFD:**

**Basic Equation:**

\[
\frac{dm_{\text{sys}}}{dt} = \sum_{\text{in}} \dot{m}_{\text{in}} - \sum_{\text{out}} \dot{m}_{\text{out}}
\]

\[
\frac{dE_{\text{sys}}}{dt} = \dot{Q} - \dot{W} + \sum_{\text{in}} \dot{m}_{\text{in}} (h + ke + pe)_{\text{in}} - \sum_{\text{out}} \dot{m}_{\text{out}} (h + ke + pe)_{\text{out}}
\]

\[ PV = mRT = \frac{mR_uT}{MW} \]
ASSUMPTIONS:
Steady State, steady flow
1-D uniform flow, uniform state
Rigid flue therefore no work
neglect kinetic and potential energy changes
air is ideal gas
air exits the flue at atmospheric pressure (100kPa)

SOLUTION:

\[ V = (0.65) \sqrt{2 \left( 9.8 \frac{m}{s^2} \right) (5m) \left( \frac{673K - 293K}{673K} \right)} = 4.84 \frac{m}{s} \]

\[ \frac{dm_{sys}}{dt} = \sum_{in} \dot{m}_{in} - \sum_{out} \dot{m}_{out} \]

\[ \dot{m}_{in} = \dot{m}_{out} \]

\[ \frac{dE_{sys}}{dt} = \dot{Q} - \dot{W} + \sum_{in} \dot{m}_{in} (h + ke + pe)_{in} - \sum_{out} \dot{m}_{out} (h + ke + pe)_{out} \]

\[ \dot{Q} = \dot{m}_{out} h_{out} - \dot{m}_{in} h_{in} = \dot{m} (h_{out} - h_{in}) \]

The velocity we have is for the hot, exiting air so we calculate for the exit conditions:

\[ \rho_{out} = \frac{P_{out} (MW)}{R_u T_{out}} = \frac{(100 \text{ kPa})(29 \frac{kg}{kmol})}{8.314 \frac{kJ}{kmol - K} (673 K)} = 0.518 \frac{kg}{m^3} \]

\[ A_{out} = 21.5cm \times 33cm \times \frac{1m^2}{10000 \text{ cm}^2} = 0.07095 \text{ m}^2 \]

Remember! We can only use \( \dot{m}_{in} = \rho VA \) if we assume that the flow is 1-D, uniform flow, uniform state, and steady flow.

\[ \dot{m}_{out} = \rho_{out} V_{out} A_{out} = 0.518 \frac{kg}{m^3} \times 4.84 \frac{m}{s} \times 0.07095 \text{ m}^2 = 0.178 \frac{kg}{s} \]

From the ideal gas tables, air:

\[ h_{in}(\text{air}, 298K) = 298.1 \frac{kJ}{kg} \]

\[ h_{out}(\text{air}, 673K) = 684.48 \frac{kJ}{kg} \]
\[ Q = \dot{m}(h_{\text{out}} - h_{\text{in}}) = 0.178 \frac{kg}{s} \left( 684.48 \frac{kJ}{kg} - 298.1 \frac{kJ}{kg} \right) = 68.7 \text{ kW} \]