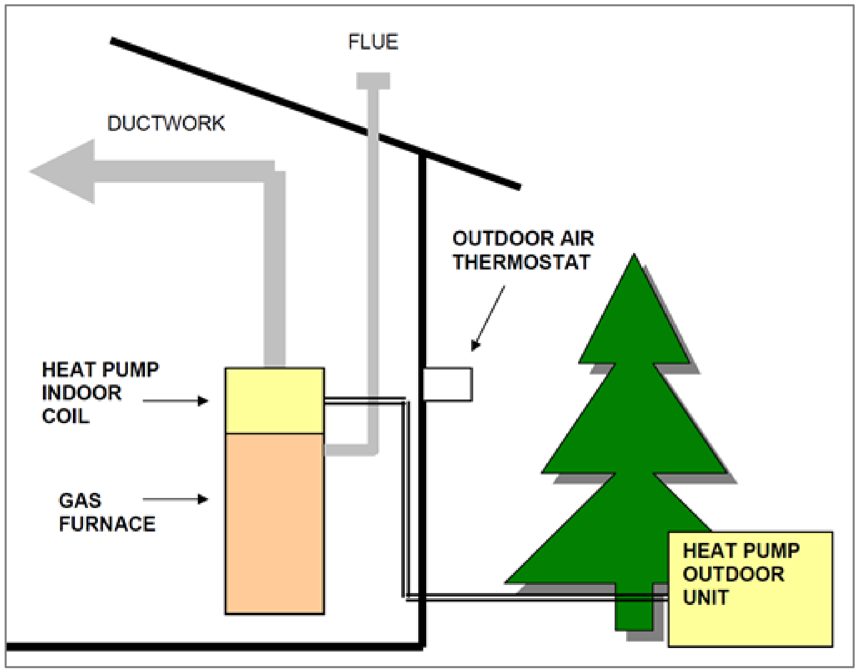
DUAL FUEL GAS HEAT & AIR SOURCE HEAT PUMP

WHITE PAPER #30

System Switches Fuels Automatically for Economy



What is an Air-Source Heat Pump?

A heat pump is a modified air conditioning system with additional devices in the refrigerant plumbing to redirect the flow of refrigerant on command. When the roles of outdoor and indoor coils are reversed, heat can be pumped inside. With this modification, the same equipment can be used to cool a house in summer and also heat it in winter. An "air source" heat pump is so-named because it gets its heat from the outdoor air. Other variations of heat pumps include water-source, ground-source, and water-to-water heat pumps; each of the designations refers to the source utilized (where heat is absorbed in winter and where heat is released in summer).

For air-source heat pumps, the heating efficiency varies directly as the difference between indoor and outdoor temperatures. In mild winter weather, such as 40 degrees F, an air-source heat pump exhibits excellent efficiency, but the efficiency drops off quickly in colder weather. Heating efficiency of heat pumps is rated in terms of the ***Coefficient of Performance*** (COP). This is a unitless measure of heat output to heat input, with higher numbers meaning higher efficiency.

A characteristic of air-source heat pumps is that as outdoor temperatures drop, the need for heating increases - meanwhile the efficiency and capacity of an air-source heat pump decreasing. Below some temperature (called the balance point) the house loses heat faster than the heat pump can provide it. For this reason, and for defrosting, air-source heat pumps are equipped with back-up resistive heaters.

Air-source heat pump efficiency drops with colder outside temperature. Efficiency will always be greater than electric heat except for the fact that it also loses heating capacity with colder outside temperature. Many ASHP units simply give up and become electric heaters below the balance temperature, meaning below the balance point, the COP drops to 1.0 (electric resistance heat). For ASHP units that keep the compressor contributing in addition to the electric heat, the COP curve doesn't drop all the way to 1.0, but will get nearer 1.0 the colder it gets, adding run hours to the compressor with less and less benefit. See **Figures 1 and 2**.

Figure 2 also shows the hours per year to expect the electric resistance heat to run. For the example shown (27F balance temp), this would be >1000 hours per year. The fuel switching aspect of this paper would be adjusted to switch over to the lower cost fuel before this happens, eliminating the high cost of electric heat and also controlling peak demand charges that could otherwise be set in cold weather.

> Note on demand charges: If your building is on an electric rate with a demand charge, this note is for you. Ignore if on energy-only rate.
>
> Without a lower cost fuel for 'morning warm up', ASHP systems will tend to produce large demands during the warmup phase. In this case, the standard conservation measure of 'night temperature set back' will likely need to either be minimized (just a few degrees of setback) or eliminated altogether. By not setting back, there will be increased energy use from building thermal loss in unoccupied time, but the cost increase from not setting back would likely be less than the bump in demand charges set during the warm-up phase when 'everything' is on. Depending on the equipment and controls, it may be possible to find middle ground with mild setbacks plus load limiting the electric heaters in stages or by floor, for a slow warm up (less kW for longer hours, starting early on cold days). Where large electric heat power demand is unavoidable, try to keep them in 'off peak' periods.

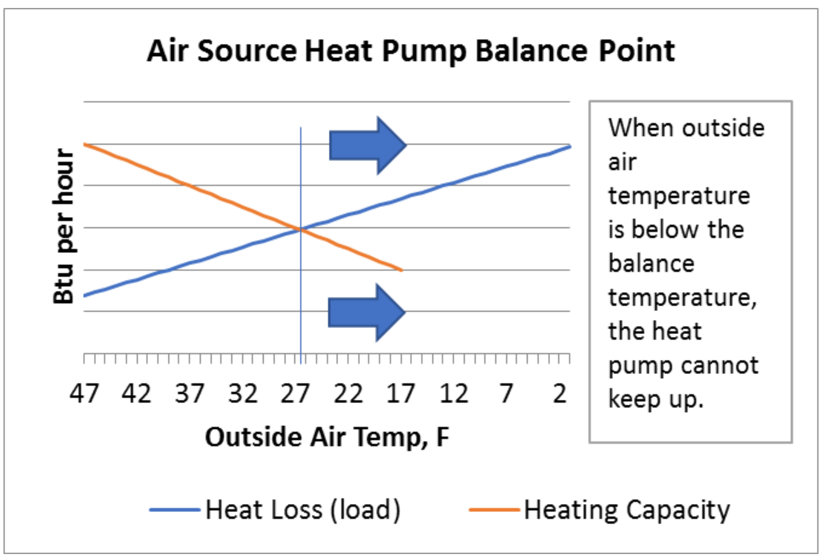


Figure 1
Air-Source Heat Pump Balance Temperature

These systems run out of capacity in cold weather and require supplemental heat provision, usually electric resistance heat.

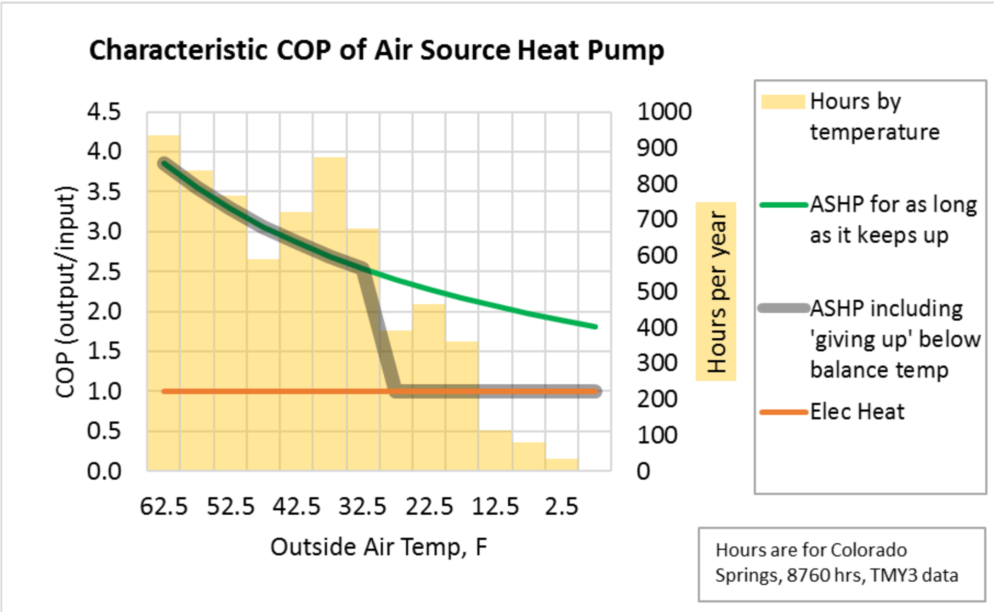


Figure 2

Air-Source Heat Pump Efficiency Decay Curve with Corresponding Hours per Year for Colorado Springs

Heating with Natural Gas or other Fuels

A common method of heating is by combustion of fossil fuels, such as natural gas. The COP for combustion heating is always less than 1.0 since some of the heat is lost to the flue with products of combustion. Modern combustion heater COPs vary from 0.8 to 0.95. Older furnaces or water heaters may be as low as 0.6 COP.

Electric Resistance Heat

This source of heat is common where heat loads are low, electric prices are low, or other sources of fuel are not available. COP for electric heat is considered to be 1.0 at the site. While conversion efficiency from electricity to heat using resistive heating is high, the cost of electricity is also high. So, while electric resistance heating is convenient and quiet, the ‘fuel’ these heaters use is expensive.

Side bar: Electricity cost

The reason for high ‘fuel’ cost for electric heating is explained by knowing how electricity is made. Conventional electricity sources are generators that convert thermal energy to mechanical energy. This is an uphill conversion from thermal energy to refined electricity energy, and nature imposes an efficiency limit. A car engine converts heat to rotational energy at about 20% efficiency – similar to a horse. A standby generator at a building (diesel or natural gas) will have a similar conversion efficiency of around 20%. Utility scale generation equipment using steam at very high pressure can achieve efficiencies of 35% or so. Combined cycle generators use waste heat from one generator to squeeze out some extra electricity achieve overall efficiencies of up to 45%. All of these ‘conventional’ conversions use a locally available fuel such as gasoline, fuel oil, natural gas. The chemical reaction of combining these with oxygen in the air releases a great deal of heat. This chemical reaction also releases $CO2$ which a driver in the move to electricity sources and vehicles that do not rely on burning a fuel.

Other electricity sources have different cost stories, and three common ones are noted. Electricity from hydro-electric, wind and solar (PV) sources also come from burning a fuel, but indirectly and in a very large furnace about 90 million miles away (the sun). This is a fuel we do not have to buy, and the fuel supply used by the sun is expected to last millions of years vs. hundreds of years for our conventional ‘fossil’ fuels on earth.

Hydro energy is solar powered, getting rotational energy from water that is moving downhill after the sun was nice enough to have lifted it up in the form of rain. The overall conversion rate for this equipment is high, however the equipment cost is high and limited to certain regions.

Wind energy is solar powered, getting rotational energy from the solar heating of the air surrounding the planet, which adds energy to the air in the form of temperature and also movement. Wind turbines are sited to capture it. Nature's limitations for wind generation are mechanical efficiencies of the blades or turbines, which are relatively low. Wind power is not dispatchable (fancy word for wind blows when it wants to), so ancillary provisions are required for times of no air movement; however, wind power works equally well – sometimes even better – at night and is a good partner for solar PV.

Sunlight energy (aka 'photo voltaic' or PV) creates electricity directly from sunlight 'photons' and a special version of semiconductor that creates usable electricity. This energy stream is not associated with heat, but still is sourced by the sun. Nature's limitation for PV generation is the efficiency of semiconductor materials and the conversion efficiency is low. PV output drops sharply when it is cloudy, and PV output is zero when it is dark outside, so energy use in the dark either comes from another source or a battery, adding ancillary cost.

Cost of electricity from hydro, wind and PV do not include fuel, which helps lower the cost of the energy for customers. But cost of electricity includes more than fuel. All energy sources have initial equipment costs and maintenance. Wind and solar PV also include redundant generating equipment and batteries that are activated whenever the wind stops and sun doesn't shine.

Conservation and demand limiting. End use efficiency measures scale cost down directly by 'using less to begin with'. Conservation and demand limiting are cost effective partners for electricity networks.

Side bar: Site vs. source energy, and the connection to heat pumps
The thrust of this paper is 'fuel switching'. The simplest application of fuel switching is where a machine has a given efficiency and can operate with different types of fuel….here, the choice of which fuel to use is based the cost per unit of fuel to produce the same output. Normally, a strategy of managing cost to heat a building or process based on comparing cost of fuel mined from units of fuel or electricity options *at the site*, vs. the unit cost for each option *at the site*. This information inset provides some background on the food chain of energy use for heating systems that helps in evaluating heat pump options, fuel switching in general – the concepts of site/source are also used by industry, utilities, or government when considering fuel supplies, generator size, or emissions. What makes it especially useful for heat pump choices is the fact that heat pump efficiency (COP) can varies considerably, especially air-source heat pumps.

Site energy is the view taken from the output side of the utility meter. It is the most common view taken by customers since it aligns directly with the utility bill. The site energy view shows electric heat efficiency to be 100%, or COP=1.0. This is accurate from the site view because electricity is easily converted to heat. For this paper we will use a 'site energy' view and consider the COP of electric heat to be 1.0 COP.

Source energy view. For completeness, here is an alternate view of energy use, called 'source energy'. This view is used when considering supplies of fuel and also for emissions calculations. Heating with electricity is an interesting case when comparing site and source energy viewpoints. The main difference between the two is source energy considers the energy used to make the electricity in the first place (plus any distribution losses when a large generator is a long way away). To illustrate, compare energy involved in producing one unit of delivered heat into a building from burning natural gas on site vs. electric heat using electricity generated upstream of the meter.

*Gas heat***.** At 80% efficiency, about 1.25 units of fuel are used at the source for one unit of heat delivered at the site.

Electric resistance heat. Conversion to heat on site is 100% efficient at the site. But if the electricity came from a fuel-fired generator that operates at 35% efficiency, with some distribution cable losses tossed in, about 3 units of fuel are used at the source for one unit of heat delivered at the site.

Electric heat using a heat pump. This technology uses a refrigeration compressor in reverse, moving heat 'into' the building rather than the usual air conditioning application that moves heat 'out of' the building. But, as noted previously, the efficiency of absorbing heat from outdoors gets lower in cold weather…which is when heat is needed the most. Here, a fixed value of COP is not used: common values are COP=3.5 at 40F outdoors and COP=1.7 at 17F outdoors. Heat pump efficiency is always greater than 1.0, but at low outside temperatures what usually happens for air source heat pumps is the capacity is too low for the load and electric resistance heat is used anyway. But, even at COP=2.0 (reasonable at 30F outside air temperature), if using electricity from a conventional generator, each unit of heat delivered to the building requires about 1.7 units of fuel. This is way better than straight electric resistance heat which underscores the statement that <u>air source heat pumps work extremely well in mild weather</u>. This also explains why air source heat pumps are very common in areas with mild winter climates. *But below the balance temperature (where the heat pump can no longer keep up), electric resistance takes over and typical air source heat pump efficiency is no better than electric resistance*. During these hours, the fuel use reverts to 3 units at the source for each delivered unit of heat at the site.

'Low temperature heat pumps' utilize additional compressor capacity at low temperature. This lowers the balance temperature and reduces the hours per year when electric resistance heaters are used, raising overall annual COP.

A 'ground source heat pump' gains seasonal efficiency by drawing its heat during winter weather from deep soil. If sufficiently deep, the soil temperature might be 50F even when it is 0F at the surface – providing heat pump efficiency equivalent to an air source heat pump on a 50F day, which might be COP 3.5. In this case, even with generator and distribution losses considered, one unit of heat at the site takes about 1 unit of source fuel.

Other heat pump notes:

- Simply oversizing a heat pump will help reduce electric resistance heat usage by moving the balance temp down but is very likely to create new problems such as short cycling at low load and loss of humidity control in cooling mode. Design strategies with heat pumps are a careful balance of efficiency and operating considerations, since one machine is being asked to do two things (heating and cooling). Two-speed or variable speed compressors are one way, but in general seek good quality advice for heat pump applications.
- Warm air produced by a heat pump is usually not as 'toasty' as from a gas furnace. For people not used to it, it may feel like cool air even though it is heating the building. This is a common complaint for air-source heat pumps in houses where the registers are at the floor. In commercial buildings with good quality ceiling diffusers

that blend room air with supply air, the effect will be less. However, it will be good to anticipate the comments. Visiting another facility that has air source heat pumps is also a good idea, to see what it feels like and to ask how they like their heat pump system.

Economics

The choice of heating source is not as simple as comparing heating efficiencies (COPs), because the ***cost per unit of fuel is different for each option.*** Electricity is sold in units of kilowatt hours, while natural gas is sold in units of hundreds of cubic feet or therms. Integrating this into the COP comparison is necessary for economic comparison. Comparing electricity and gas as heating 'fuel' options:

Heating with gas can create savings…

- When heat pump efficiency is low and when the unit is below the balance temperature
- Any time the electric heaters would be running.

Heating with electricity can create savings…

- When heat pump COP is high enough and above the balance temperature so that electric heat does not run.

Savings potential for the hybrid air-source heat pump with gas heater lies in the ability to switch from electric to gas when the temperature is low enough that gas becomes more cost efficient to use. With the systems in place, it is a simple adjustment, however the magic switching temperature will vary over time as the cost of each fuel varies. In words, the switch point exists where:

*$ per Btu of natural gas * (1/gas heater eff) = $ per Btu of electricity / heat pump COP*

The economic switch point will definitely be above the balance temperature (the point below which it is all electric resistance heat), but how far above it? The precise answer comes with considerable math, but with a few assumptions, this yes/no chart can get you very close, very quickly. Since the switch point depends on the ratio of the two rates, it's a good idea to check the economic switch point each time the rates change (gas or electric).

→Notes for Tables 1 and 2: Estimated Outside Air Temperatures for Economical Fuel Switching Between Air Source Heat Pump Natural Gas Heat

- There are separate tables for 80% and 90+% efficient gas heaters. Choose the appropriate table.
- Find the block of data that matches the intersection of current blended rates for natural gas and electricity, such as $0.10 per kwh and $0.60 per ccf.
- Look at the block to find a reasonable setting. These are close, not exact.
- If the whole block says "electric", then use electricity for the full range of outside temperatures but switch to natural gas below the range if reverting to straight electric heat.
- If the whole block says "gas", then use gas for the full range of outside temperature.
- If the block shows temperature where it switches between electric and gas, the economic switch point is somewhere in that 5F range. A suggestion is to set your switchover control to the higher value of outside air. You'll be very close to the economical switch point, erring on the comfortable side.
- If the heat pump is not comfortable, try adjusting air registers if blowing down onto people, or setting the switchover value 5F higher (to use gas heat sooner).
- The chart presumes the heat pump compressor is active for all temperatures indicated, without electric resistance heat. Below the balance temperature, if reverting to straight electric heat, the unit efficiency drops sharply **(Fig 2).** Where the chart indicates economical electric heat pump operation even at the lowest value of OA on the chart, it is still more economical to use natural gas whenever straight electric heat is otherwise used.

Assumptions used in creating the table values

- Basis is energy use and dollars per delivered Btu, after equipment efficiency losses. Level of accuracy is 'good approximation' for most customers that have heating fuel options and air source heat pumps.
- Compared calculated values for the fuels use blended rates, i.e. total dollars per month divided by total kWh per month for electricity; similar for ccf of natural gas. Blended rates should be a good fit for most customers, since heating occurs across most business hours during heating season. However, there is always some Inaccuracy from using blended rates, including the presence of large short-term demands or when usage is not distributed across all operating hours including on/off peak period. Use other means if exact values are needed.
- Tables show heating begins at and below 65F and will fit many commercial and residential customers that use heat pumps. Where there are significant internal loads such, the heating 'starting point' will be lower, in which case ignore the 65F data rows and begin with the outside air temperature that matches your facility.
- Heat pump COP calculated linearly between COP=3.8 (at 65F OA) and COP=2.5 (at 30F), which are representative equipment values. Where actual COP of heat pumps is considerably higher (better) than assumed values, the economic switch point for natural gas will be lower.
- Heat pump balance temperature is assumed to be 30F, below which the heat pump compressor turns off and the unit operates as straight electric heat.

Table 1. Estimated Outside Air Temperatures for Economical Fuel Switching Between Air Source Heat Pump and 80% efficient Natural Gas Heat

→ See separate notes for table use and assumptions ←

80% gas heat: Which is less expensive to run? Gas or Electric Heat Pump?

Outside Air temp	$/ccf Gas	$0.08 $/kWh Elec	$0.09 $/kWh Elec	$0.10 $/kWh Elec	$0.11 $/kWh Elec	$0.12 $/kWh Elec	$0.13 $/kWh Elec	$0.14 $/kWh Elec	deg F
65	$0.40	Gas	Gas	Gas	Gas	Gas	Gas	Gas	65
60		Gas	Gas	Gas	Gas	Gas	Gas	Gas	60
55		Gas	Gas	Gas	Gas	Gas	Gas	Gas	55
50		Gas	Gas	Gas	Gas	Gas	Gas	Gas	50
45		Gas	Gas	Gas	Gas	Gas	Gas	Gas	45
40		Gas	Gas	Gas	Gas	Gas	Gas	Gas	40
35		Gas	Gas	Gas	Gas	Gas	Gas	Gas	35
30		Gas	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.50	Electric	Electric	Gas	Gas	Gas	Gas	Gas	65
60		Electric	Electric	Gas	Gas	Gas	Gas	Gas	60
55		Electric	Gas	Gas	Gas	Gas	Gas	Gas	55
50		Electric	Gas	Gas	Gas	Gas	Gas	Gas	50
45		Gas	Gas	Gas	Gas	Gas	Gas	Gas	45
40		Gas	Gas	Gas	Gas	Gas	Gas	Gas	40
35		Gas	Gas	Gas	Gas	Gas	Gas	Gas	35
30		Gas	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.60	Electric	Electric	Electric	Electric	Gas	Gas	Gas	65
60		Electric	Electric	Electric	Gas	Gas	Gas	Gas	60
55		Electric	Electric	Electric	Gas	Gas	Gas	Gas	55
50		Electric	Electric	Gas	Gas	Gas	Gas	Gas	50
45		Electric	Electric	Gas	Gas	Gas	Gas	Gas	45
40		Electric	Gas	Gas	Gas	Gas	Gas	Gas	40
35		Electric	Gas	Gas	Gas	Gas	Gas	Gas	35
30		Gas	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.70	Electric	Electric	Electric	Electric	Electric	Electric	Gas	65
60		Electric	Electric	Electric	Electric	Electric	Gas	Gas	60
55		Electric	Electric	Electric	Electric	Electric	Gas	Gas	55
50		Electric	Electric	Electric	Electric	Gas	Gas	Gas	50
45		Electric	Electric	Electric	Gas	Gas	Gas	Gas	45
40		Electric	Electric	Electric	Gas	Gas	Gas	Gas	40
35		Electric	Electric	Gas	Gas	Gas	Gas	Gas	35
30		Electric	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.80	Electric	Electric	Electric	Electric	Electric	Electric	Electric	65
60		Electric	Electric	Electric	Electric	Electric	Electric	Electric	60
55		Electric	Electric	Electric	Electric	Electric	Electric	Gas	55
50		Electric	Electric	Electric	Electric	Electric	Gas	Gas	50
45		Electric	Electric	Electric	Electric	Electric	Gas	Gas	45
40		Electric	Electric	Electric	Electric	Gas	Gas	Gas	40
35		Electric	Electric	Electric	Gas	Gas	Gas	Gas	35
30		Electric	Electric	Electric	Gas	Gas	Gas	Gas	30
65	$0.90	Electric	Electric	Electric	Electric	Electric	Electric	Electric	65
60		Electric	Electric	Electric	Electric	Electric	Electric	Electric	60
55		Electric	Electric	Electric	Electric	Electric	Electric	Electric	55
50		Electric	Electric	Electric	Electric	Electric	Electric	Electric	50
45		Electric	Electric	Electric	Electric	Electric	Electric	Gas	45
40		Electric	Electric	Electric	Electric	Electric	Gas	Gas	40
35		Electric	Electric	Electric	Electric	Electric	Gas	Gas	35
30		Electric	Electric	Electric	Electric	Gas	Gas	Gas	30

Chart assumes heat pump operates at all OA temps shown, and the lowest temp is the balance point. Where rate combinations show the heat pump is more economical than gas at the balance temperature, natural gas will still be more economical below this temperature if reverting to straight electric heat.

Table 2. Estimated Outside Air Temperatures for Economical Fuel Switching Between Air Source Heat Pump and 90% efficient Natural Gas Heat

→ See separate notes for table use and assumptions ←

90% gas heat: Which is less expensive to run? Gas or Electric Heat Pump?

Outside Air temp	$/ccf Gas	$0.08 $/kWh Elec	$0.09 $/kWh Elec	$0.10 $/kWh Elec	$0.11 $/kWh Elec	$0.12 $/kWh Elec	$0.13 $/kWh Elec	$0.14 $/kWh Elec	deg F
65	$0.40	Gas	Gas	Gas	Gas	Gas	Gas	Gas	65
60		Gas	Gas	Gas	Gas	Gas	Gas	Gas	60
55		Gas	Gas	Gas	Gas	Gas	Gas	Gas	55
50		Gas	Gas	Gas	Gas	Gas	Gas	Gas	50
45		Gas	Gas	Gas	Gas	Gas	Gas	Gas	45
40		Gas	Gas	Gas	Gas	Gas	Gas	Gas	40
35		Gas	Gas	Gas	Gas	Gas	Gas	Gas	35
30		Gas	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.50	Electric	Gas	Gas	Gas	Gas	Gas	Gas	65
60		Electric	Gas	Gas	Gas	Gas	Gas	Gas	60
55		Gas	Gas	Gas	Gas	Gas	Gas	Gas	55
50		Gas	Gas	Gas	Gas	Gas	Gas	Gas	50
45		Gas	Gas	Gas	Gas	Gas	Gas	Gas	45
40		Gas	Gas	Gas	Gas	Gas	Gas	Gas	40
35		Gas	Gas	Gas	Gas	Gas	Gas	Gas	35
30		Gas	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.60	Electric	Electric	Electric	Gas	Gas	Gas	Gas	65
60		Electric	Electric	Gas	Gas	Gas	Gas	Gas	60
55		Electric	Electric	Gas	Gas	Gas	Gas	Gas	55
50		Electric	Gas	Gas	Gas	Gas	Gas	Gas	50
45		Electric	Gas	Gas	Gas	Gas	Gas	Gas	45
40		Gas	Gas	Gas	Gas	Gas	Gas	Gas	40
35		Gas	Gas	Gas	Gas	Gas	Gas	Gas	35
30		Gas	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.70	Electric	Electric	Electric	Electric	Gas	Gas	Gas	65
60		Electric	Electric	Electric	Electric	Gas	Gas	Gas	60
55		Electric	Electric	Electric	Gas	Gas	Gas	Gas	55
50		Electric	Electric	Electric	Gas	Gas	Gas	Gas	50
45		Electric	Electric	Gas	Gas	Gas	Gas	Gas	45
40		Electric	Gas	Gas	Gas	Gas	Gas	Gas	40
35		Electric	Gas	Gas	Gas	Gas	Gas	Gas	35
30		Gas	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.80	Electric	Electric	Electric	Electric	Electric	Electric	Gas	65
60		Electric	Electric	Electric	Electric	Electric	Gas	Gas	60
55		Electric	Electric	Electric	Electric	Electric	Gas	Gas	55
50		Electric	Electric	Electric	Electric	Gas	Gas	Gas	50
45		Electric	Electric	Electric	Gas	Gas	Gas	Gas	45
40		Electric	Electric	Electric	Gas	Gas	Gas	Gas	40
35		Electric	Electric	Gas	Gas	Gas	Gas	Gas	35
30		Electric	Gas	Gas	Gas	Gas	Gas	Gas	30
65	$0.90	Electric	Electric	Electric	Electric	Electric	Electric	Electric	65
60		Electric	Electric	Electric	Electric	Electric	Electric	Electric	60
55		Electric	Electric	Electric	Electric	Electric	Electric	Gas	55
50		Electric	Electric	Electric	Electric	Electric	Gas	Gas	50
45		Electric	Electric	Electric	Electric	Electric	Gas	Gas	45
40		Electric	Electric	Electric	Electric	Gas	Gas	Gas	40
35		Electric	Electric	Electric	Gas	Gas	Gas	Gas	35
30		Electric	Electric	Electric	Gas	Gas	Gas	Gas	30

Chart assumes heat pump operates at all OA temps shown, and the lowest temp is the balance point. Where rate combinations show the heat pump is more economical than gas at the balance temperature, natural gas will still be more economical below this temperature if reverting to straight electric heat.