RESIDENTIAL HEAT PUMP LIFE CYCLE CLIMATE PERFORMANCE (LCCP) IN NORTH AMERICA

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Overview

Study to assess annual differences in :

- Operating cost
- Site energy consumption
- Primary energy consumption, and
- Greenhouse gas emissions (GHG)

Between two common residential space conditioning systems in North America:

- Central Air Conditioner + Warm Air Natural Gas Furnace
- Electric Air-to-Air Heat Pump

Data Sources

Residential site energy costs are taken from the US Dept. of Energy 2010 Residential Nationally-Averaged Energy Costs, published in the Congressional Federal Register
http://www.gpo.gov/fdsys/pkg/FR-2010-03-18/html/2010-5936.htm

$0.1150 per kWh for electricity consumed at site
$0.0407 per kWh(t) for natural gas consumed at site

Data Sources, (continued)

Factors for source energy and GHG emissions associated with site energy consumption come from Source Energy and Emission Factors for Energy Use in Buildings, M. Deru and P. Torcellini, 2007. This is National Renewable Energy Laboratory Report: NREL/TP-550-38617 http://www.nrel.gov/docs/fy07osti/38617.pdf

Data Sources, (continued)

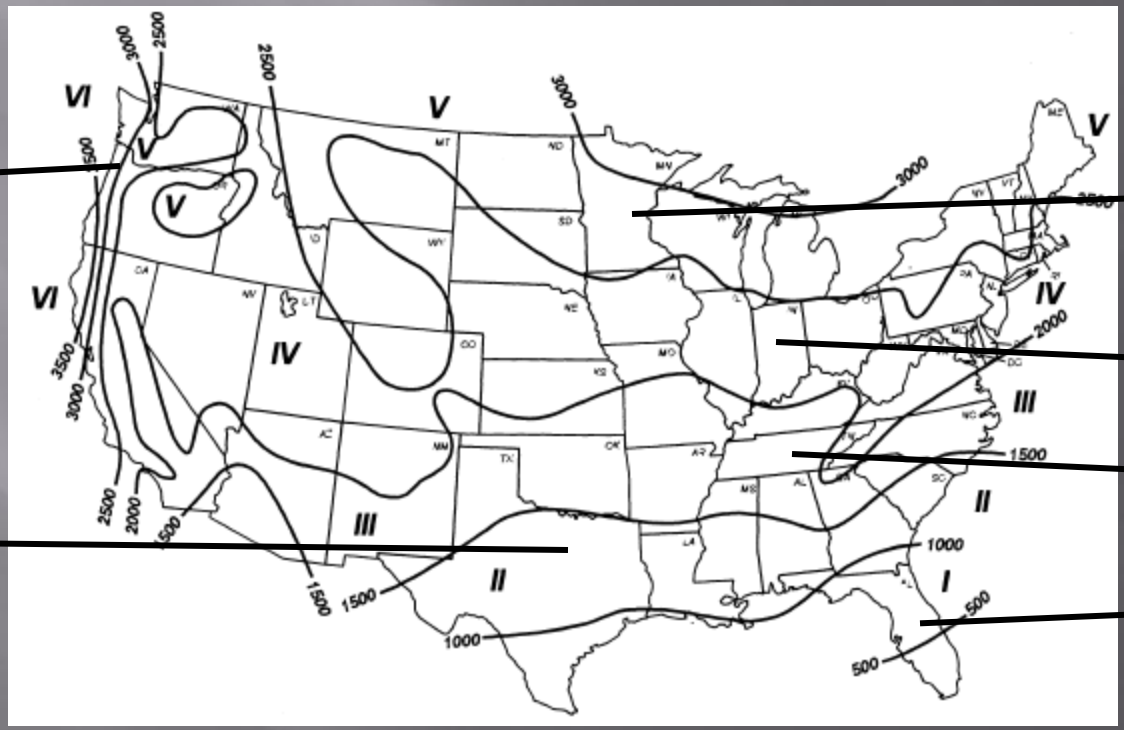
Heating and Cooling Equipment Performance (capacity & efficiency – vs.- outdoor temperature) comes from AHRI certified equipment and, in the case of heat pumps, has been extended to properly represent operation for six defined climatological regions.

The GHG Factor for refrigerant R410A* and the assumed equipment refrigerant leakage rate comes from a 2002 Arthur D. Little study: Global Comparitive Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant and Fire Protection Applications.

*All vapor compression systems evaluated use R410A.

Data Sources, (continued)

Six cities were chosen to represent each of the six climatological regions defined by the US DoE Test Procedure for Residential Central Air and Heat Pumps.



Data Sources, (continued)

For AC + Gas Furnace:

- Northern cities used 13 SEER condensers and 90 AFUE furnaces
- Southern cities used 14 SEER condensers and 80 AFUE furnaces

Heat Pumps were always 14 SEER / 8.5 HSPF (Region IV)

Weather Data for the cities are from the 2009 edition of the ASHRAE Handbook of Fundamentals.

Annual Site Energy Consumption and Operating Costs for Gas Furnace + Central Air Conditioner

Cooling

City	DOE Region	Mini-mum SEER	Corres-ponding Seasonal CCOP	Cooling Load (kWh)	Cooling Electrical Energy Use (kWh)	Cooling Season Operating Cost @ $0.115/kWh ($)
Orlando	I	14	4.10	21100	5143	591
Ft. Worth	II	14	4.10	19000	4629	532
Nashville	III	14	4.10	10500	2571	296
Indianapolis	IV	13	3.81	5600	1477	170
Minneapolis	V	13	3.81	2800	738	85
Portland	VI	13	3.81	1200	324	37

Heating

City	DOE Region	Min. AFUE	Furnace Electrical Power (kW)	Heating Load (kWh)	Natural Gas HHV Fuel Input (kWh thermal)	Heating Electrical Energy Use (kWh)	Heating Season Op. Cost @ $0.115/kWh & $0.04074/kWh (thermal)
Orlando	I	80	0.5	3600	4400	375	224
Ft. Worth	II	80	0.6	9600	12100	750	578
Nashville	III	80	0.5	14200	17800	875	825
Indianapolis	IV	90	0.4	22900	25400	900	1138
Minneapolis	V	90	0.6	35700	39700	1650	1808
Portland	VI	90	0.4	13000	14500	1100	716

Annual Site Energy Consumption and Operating Costs for Heat Pump

Cooling

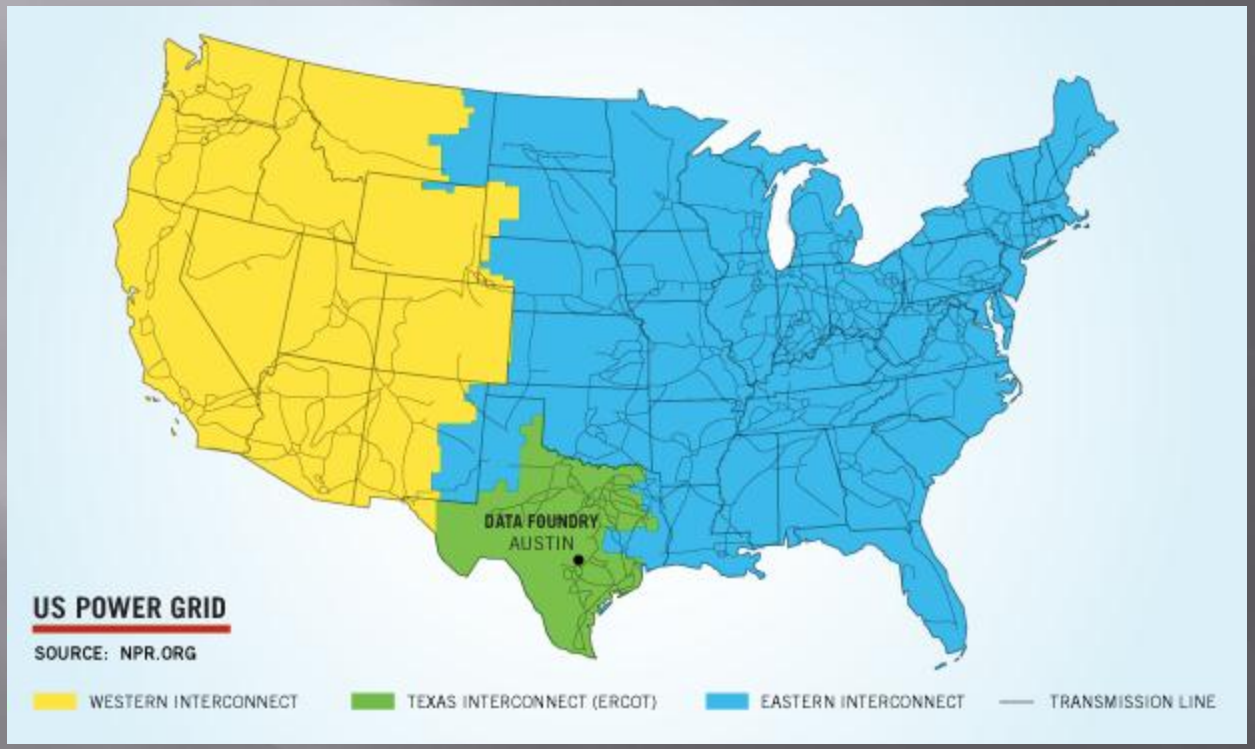
City	DOE Region	SEER	Cooling COP	Cooling Load (kWh)	Cooling Electrical Energy Use (kWh)	Cooling Season Operating Cost @ $0.115/kWh ($)
Orlando	I	14	4.103	21100	5143	591
Ft. Worth	II	14	4.103	19000	4629	532
Nashville	III	14	4.103	10500	2571	296
Indianapolis	VI	14	4.103	5600	1371	158
Minneapolis	V	14	4.103	2800	686	79
Portland	VI	14	4.103	1200	301	35

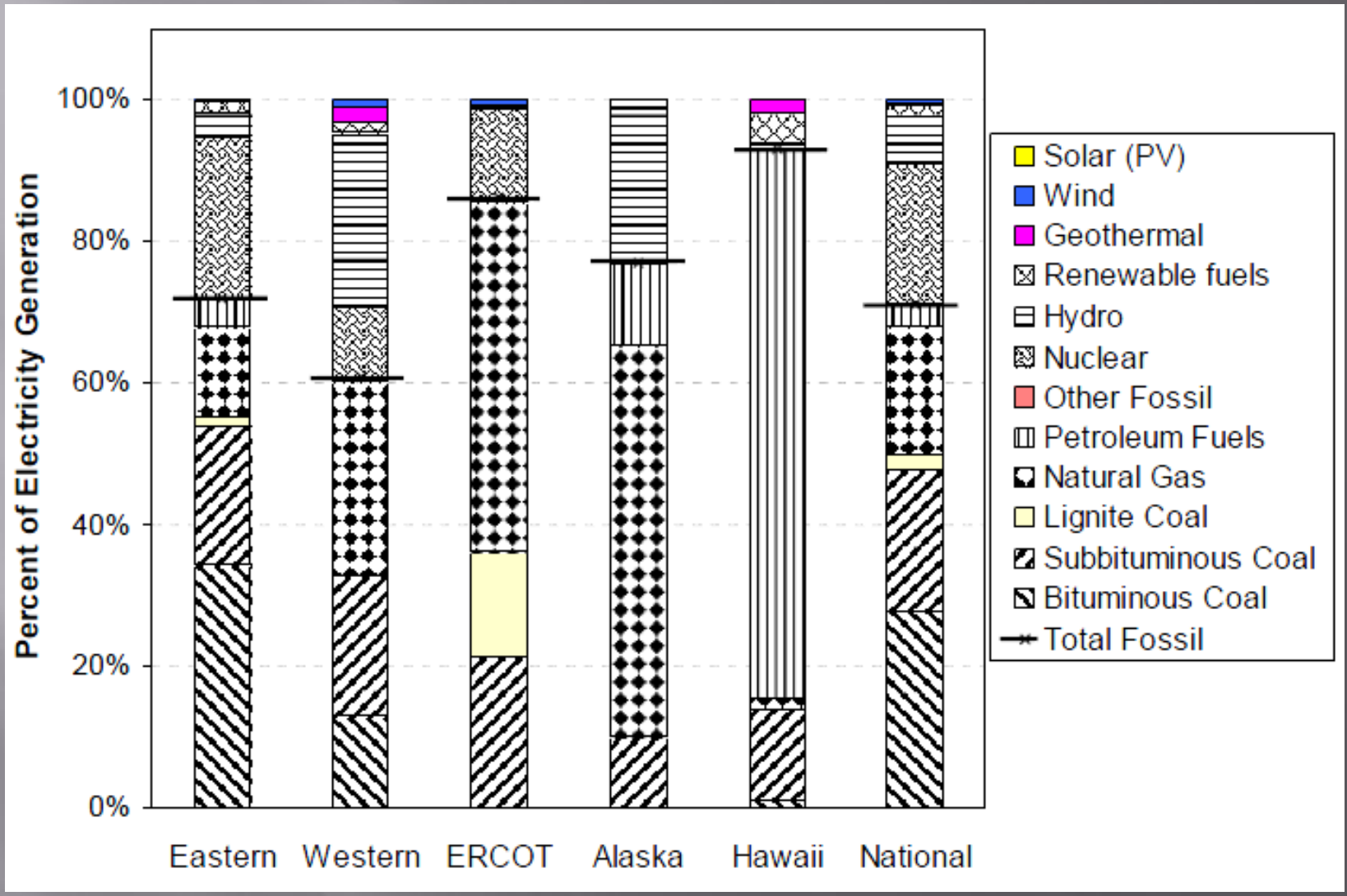
Heating

City	DOE Region	Region IV (min DHR) HSPF	"Cool-ing Over-size Factor"	HSPF for mid-DHR, Region, Sizing Factor	Heating COP	Heating Load (kWh)	Heating Electrical Energy Use (kWh)	Heating Season Operating Cost @ $0.115/ kWh ($)
Orlando	I	8.5	1	10.59	3.10	3600	1144	130
Ft. Worth	II	8.5	1	9.96	2.92	9600	3300	380
Nashville	III	8.5	1	9.27	2.72	14200	5200	600
Indianapolis	IV	8.5	1.25	8.21	2.41	22900	9500	1100
Minneapolis	V	8.5	1.5	6.73	1.97	35700	18000	2100
Portland	VI	8.5	1.14	10.27	3.01	13000	4300	500

The Continental US has three large electrical “interconnects”

- Western
- ERCOT (most of Texas)
- Eastern





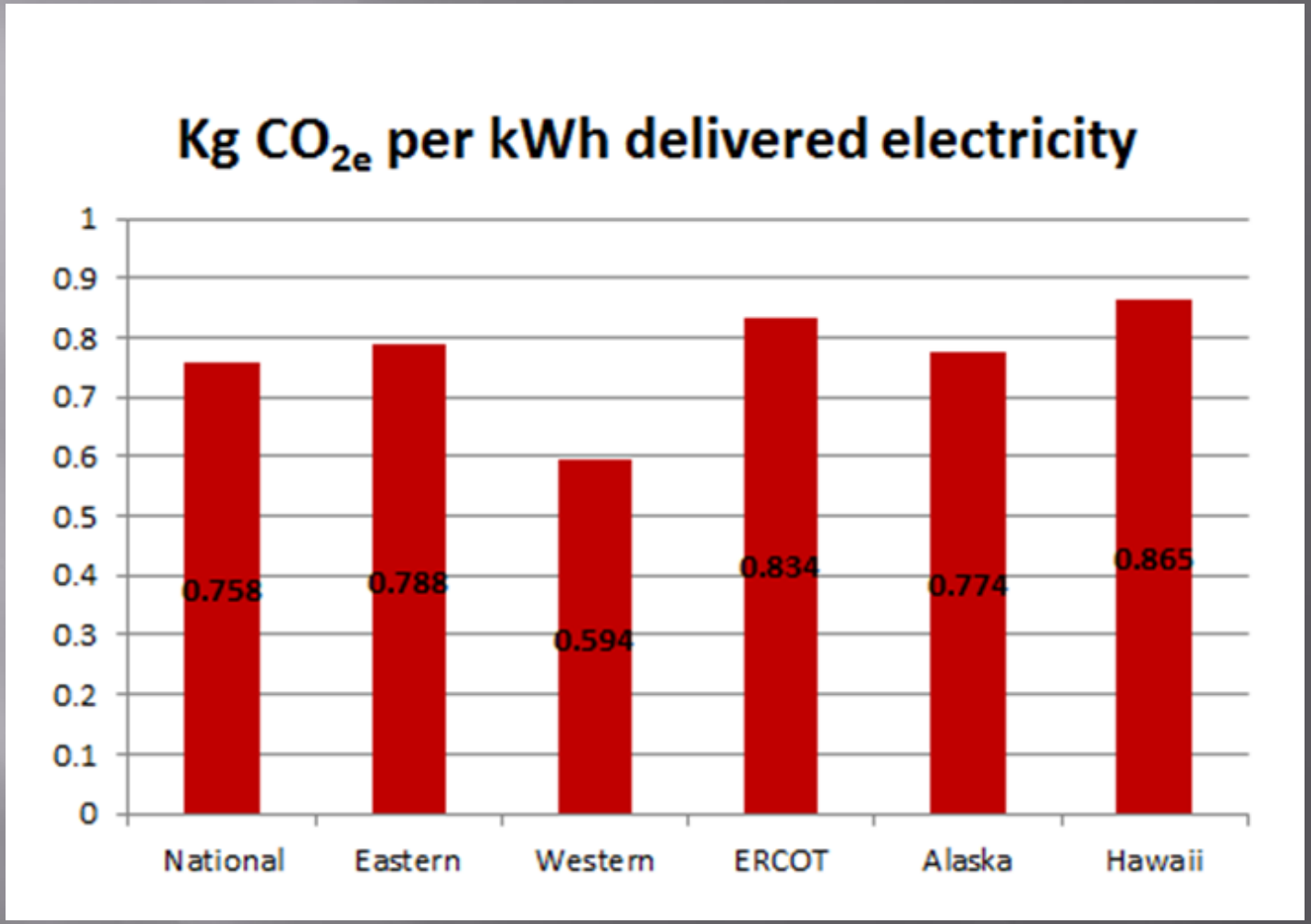
Electricity generation fuel mix for US – National (lower forty eight), AK, HI, and Regional averages.

Full-Fuel Cycle Losses

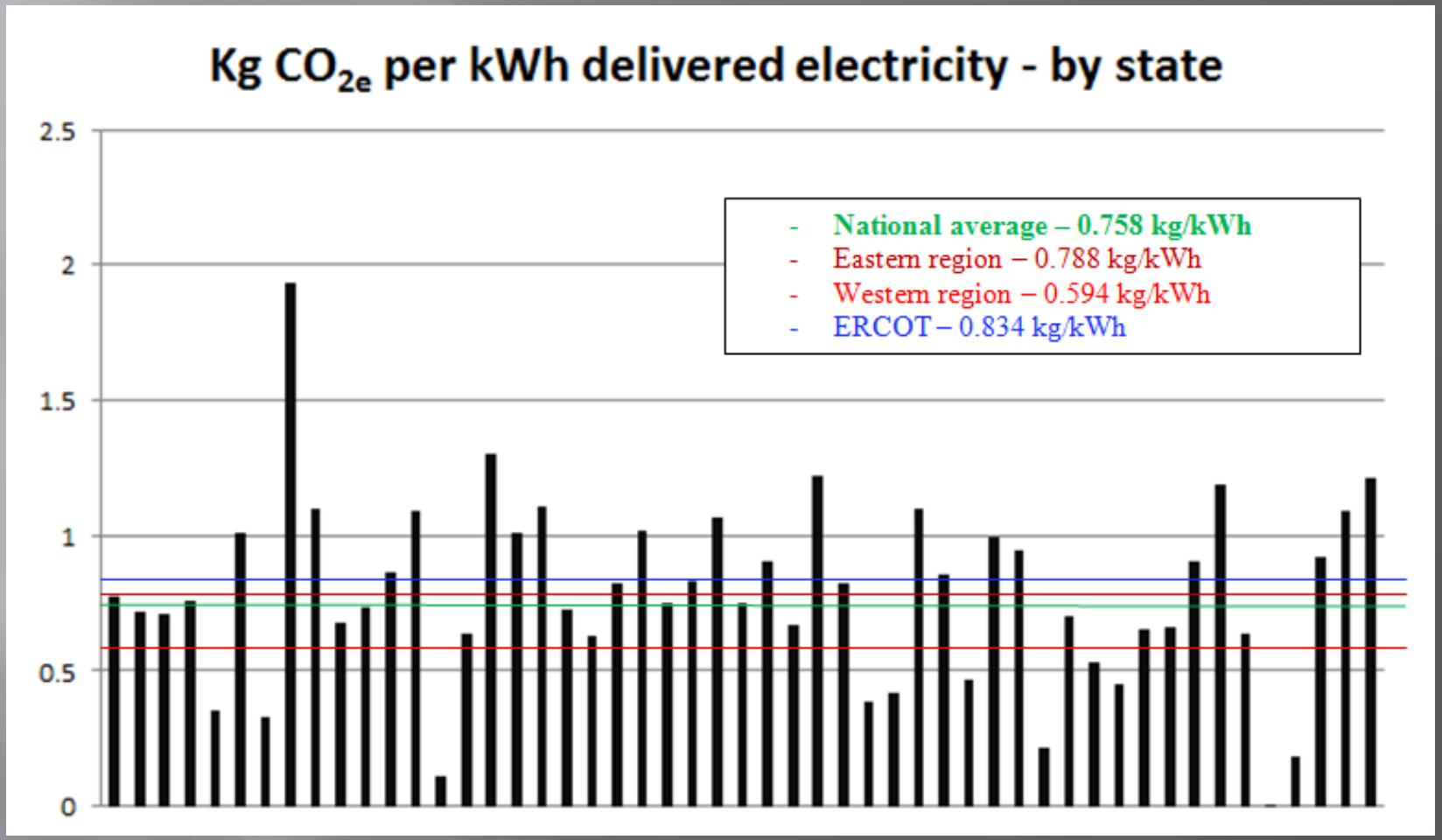
Delivered electrical energy has inefficiencies and losses going back through the energy supply system. For this study, these losses are taken into account based upon the interconnect region:

- Pre-combustion loss
- Generation loss
- Transmission loss

For natural gas energy delivery, there are also upstream losses. For this study, the same upstream loss (9%) is used for all sites.

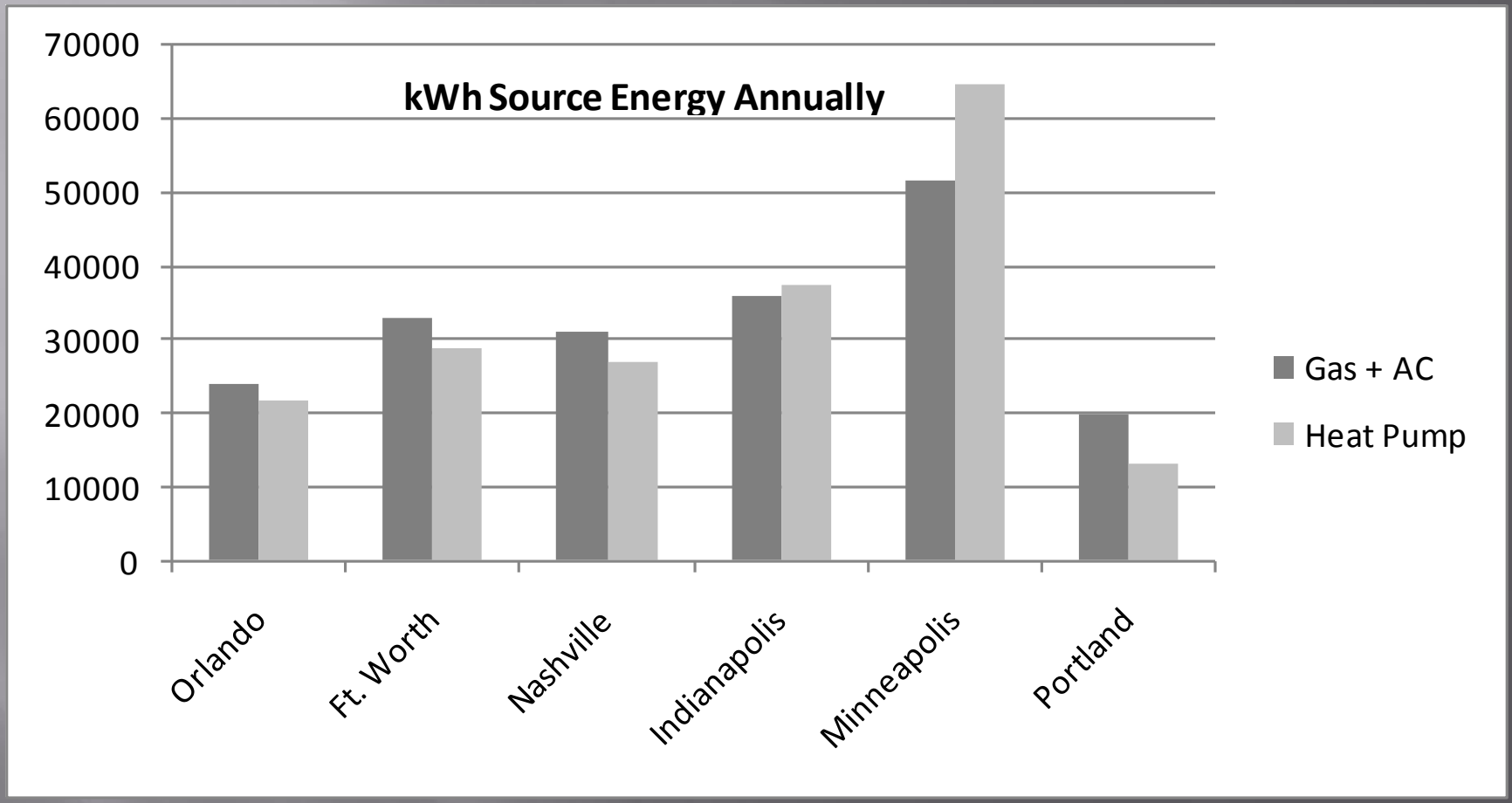


For natural gas, a national average emission factor for residential furnace combustion of 0.00238 kg/m^3 (includes transmission, etc., losses to deliver the fuel to the building) was used for all sites in the present analysis.



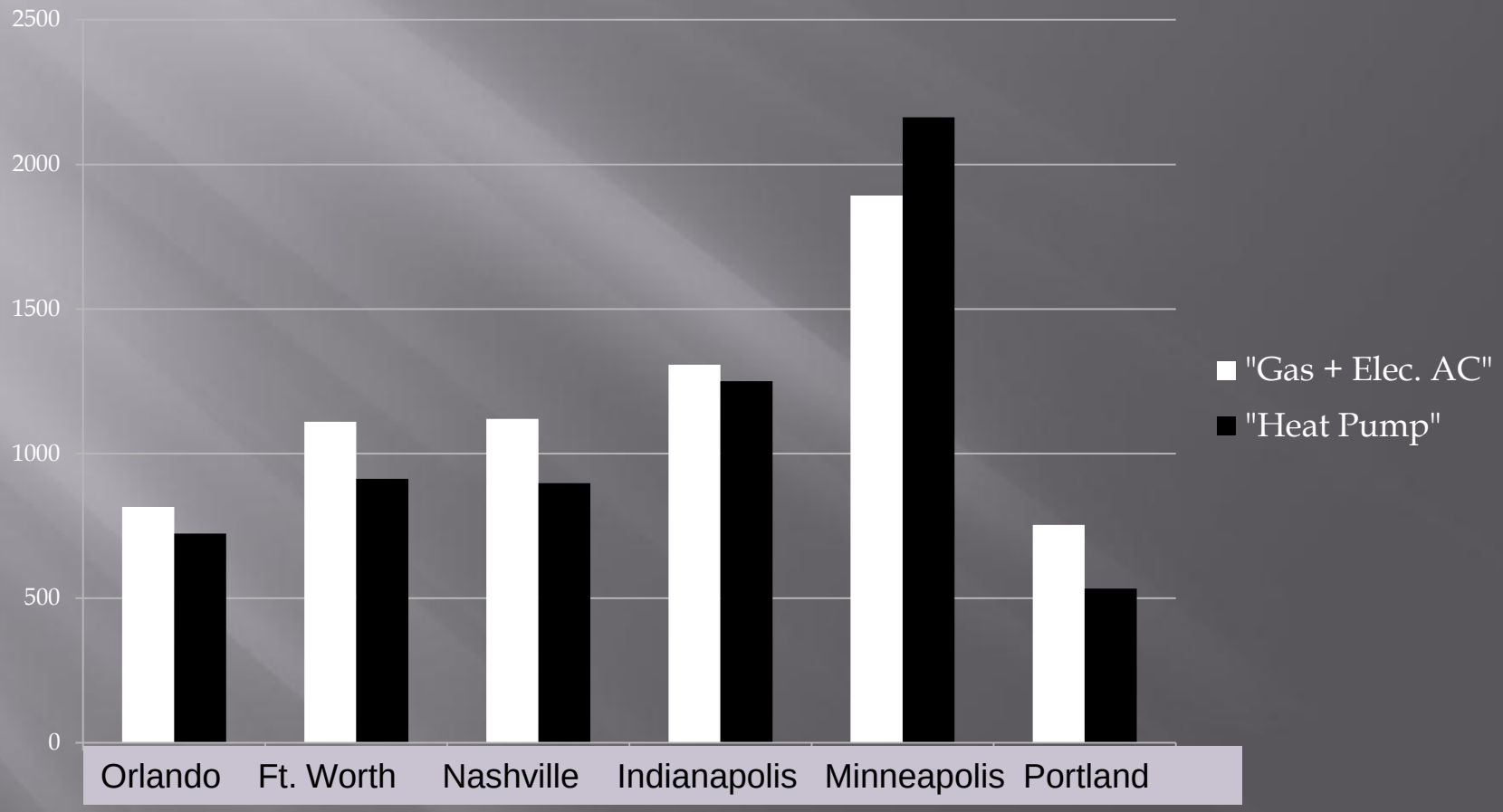
For a particular state, it is difficult to know the electrical generation source. Many import a significant fraction of their electric power from neighboring states and/or Canada (varies with time of year). Average regional emission factors were used for each site in this analysis. CO_{2e} => sum of CO_2 and CO_2 equivalent emissions of CH_4 and N_2O.

Annual Full-Fuel Cycle Energy for Two HVAC Alternatives in Six Cities

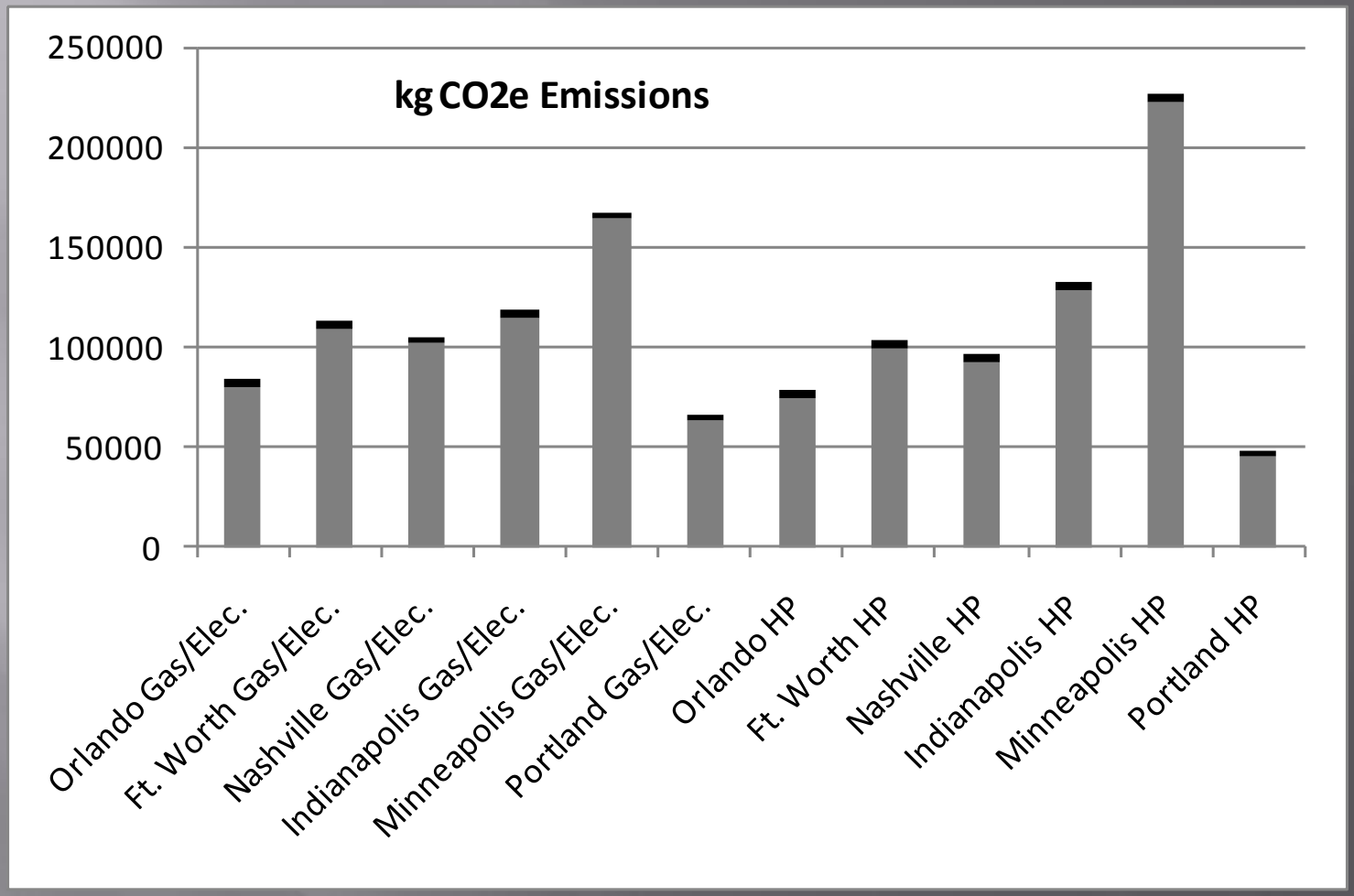


Heat Pump has lowest primary energy consumption except for Indianapolis and Minneapolis.

Estimated Annual HVAC Operating Cost ($)



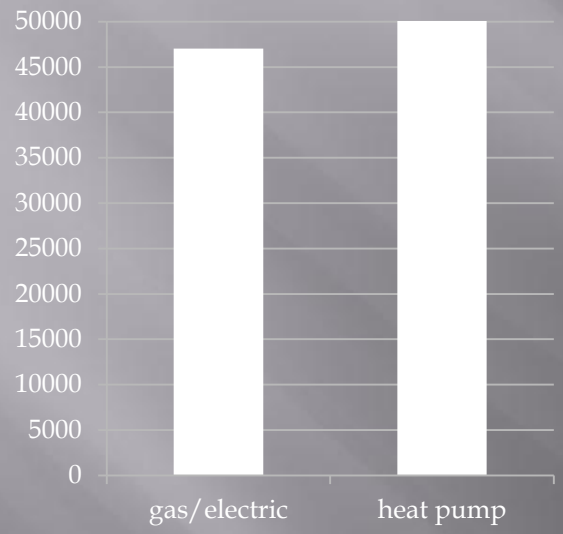
CO_{2e} Emissions Over 15 Year Life



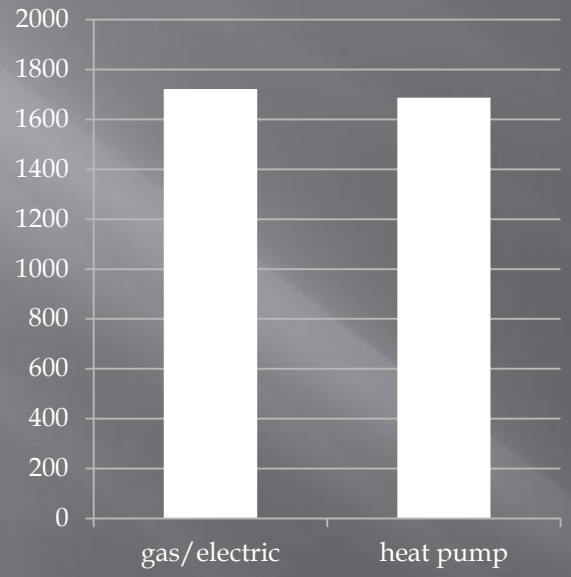
As with primary energy, the heat pump is lowest in all cities except Indianapolis and Minneapolis.
Black bar at top of columns represents GHG impact of R410A loss.

Comparison of "Best" HVAC Alternatives: Minneapolis, MN

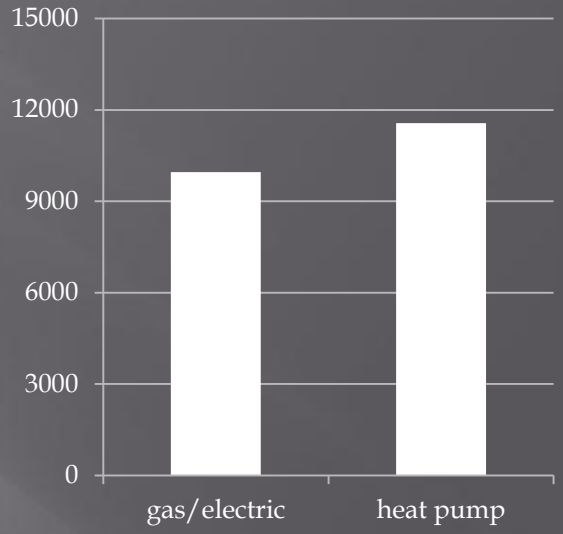
Annual Full-Fuel Cycle Energy Use (kWh thermal)



Estimated Annual Operating Cost ($)



CO_{2e} Emissions Over 15 Year Life (kgs)



"Best" Equipment Specifications:

Gas Furnace + Electric AC ≡ 98 AFUE and 13 SEER (3.8 cooling SPF)

2 Stage Heat Pump ≡ 8.42 Region V HSPF and 17.4 SEER (2.47 & 5.10 heating & cooling SPFs, respectively)

- HP was oversized:
  - ~17.5kW nominal cooling capacity at high capacity stage
  - only 1st (low) stage capacity used for space cooling

Concluding Observations

Study purpose was to assess annual differences in annual operating costs, energy consumption and CO_{2e} emissions between two of the most commonly used residential space conditioning systems in North America:

- Central Air Conditioner + Warm Air Natural Gas Furnace
- Electric Air-to-Air Heat Pump

For baseline efficiency options:

- the heat pump option has the advantage in Portland, Ft. Worth, Nashville, and Orlando (milder winter climates);
- the gas/AC option has slightly better source energy and CO_{2e} emission performance and the heat pump slightly lower operating cost in Indianapolis (Region IV); and
- the gas/AC option has the advantage in Minneapolis (cold climate)

For “Best” efficiency options in Minneapolis -

- The two-stage heat pump has slightly lower operating cost and the gas/AC slightly lower source energy use and CO_{2e} emissions
- An increase in heating SPF to 2.9 (~17% improvement) would enable the heat pump to achieve equal CO_{2e} emissions and lower energy use than the gas/AC option
    - both capacity and efficiency boost options should be investigated to improve low temperature performance for the heat pump