GSHPs and ASHPs Real Performance Results in Cold Climates



University of Minnesota Cold Climate Housing Program Center for Sustainable Building Research (CSBR) Center for Energy and Environment (CEE) GSHPs and ASHPs - Real Performance Results in Cold Climates

Outline

- 1) Ground source heat pump monitoring project
 - i. Background
 - ii. Monitoring
 - iii. Modeling
- 2) Air source heat pump monitoring project
 - i. Background
 - ii. Monitoring Results
- 3) Discussion, comparison, & implications for Passive House



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GSHP - background

Prior research:

Michaels Engineering Report for MN Department of Commerce (2008)

- Found negative life cycle savings and increased CO2 emissions for residential installations.
- 2) Widely criticized by the GSHP industry for using modeled energy results based on assumed GSHP efficiency levels.
- 3) Assumed 3.3 heating COP, 4.1 cooling COP for the energy modeling study



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GSHP - background

University of Minnesota's Cold Climate Housing Program proposed revised research approach:

- 1) Multi-year in-situ monitoring of GSHP systems
- 2) Energy modeling comparison to standard GFA systems using COP results from monitoring
- 3) Broader environmental and policy assessment of GSHP technology, including an LCA study





Original goal: 50 monitored systems in various climate zones

After drop-outs, equipment failures and data issues, 37 systems were used for the report.

Monitoring system design and installation provided by Mike LeBeau, CR Building Performance Specialists.

05-Jan-14 4:0	51.4	51.4	0 52	51.4	0 0 0.7 0.3	0 0.5 0.1 0	0 1	18.7 18.775 18.6 0 11.8 10.125 15.8 19.375 12.1 10.65 15.2 18.225 67.3 70.075 -15.575 0.025 17 0.0 15.04.45 10 10.005 10 0.1 11.6 10 10 10 10 10 10 10 10 10 10 10 10 10	15,531.0 0.0 2,388.5 1,023.6 0.0 1,706.1
05-Jan-14 530 05-Jan-14 630	50.8	50.8 60	0 51.5	50.7	0 0 0.5 0.3	0 0.5 0 0		12 22/07 12 01 116 77 347 336 308 318 888 83.27 897 8607 135 0885 33.6 038 03.2380 0 229 229 0 114 118 342 34.25 20.3 20425 16.7 56.675 64.7 64.55 17.35 0.855 3.8 0.0 28.121.5	15,865.0 83.5 2,047.5 1,025.6 0.0 1,706.1 19,121.5 0.0 2,729.7 1,364.9 0.0 1,706.1
05-Jan-14 7:0	60	60	0 60	60	0 0 0.7 0.4	0 0.6 0 0	0 1	22.7 22.675 22.7 0 12 11.8 33.9 34.005 30.1 30.175 86.4 86.575 69.4 69.465 18.55 0.885 3.9 218.890.2 38.954.5	18,954.5 0.0 2,388.5 1,364.9 0.0 2,047.3
05-Jan-14 8:0 05-Jan-14 9:0	60 47.6	42.6	0 60	47.7	0 0 0.0 0.5	0 0.5 0.1 0	0 1	227 22.725 22.7 0 11.7 11.75 13.14 33.9 30 36075 86.4 84.325 66.4 64.15 -19.45 0.815 3.4 0.0 38,984.5 177 15.75 17.4 6 0 9 34 36.5 3.4 0.0 38,984.5 17.5 17.5 17.5 17.5 18.45 19.45 0.895 3.4 0.0 38,984.5 11.5 11.5 11.5 11.5 11.5 11.5 11.5 1	18,954.5 0.0 2,729.7 1,706.1 0.0 1,706.1 14,696.0 0.0 1,706.1 1,023.6 0.0 1,706.1
05-Jan-14 10:	58.2	58.2	0 58.2	58.1	0 0 0.9 0.4	0 0.5 0 0	0 1	21.1 21.225 23.1 0 11.7 11.525 33.9 34.375 30.1 30.375 86.9 86.525 70.2 69.475 42.125 0.815 4.0 0.0 29.286.5	19,288.5 0.0 3,070.9 1,364.9 0.0 1,706.1
05-Jan-14 11: 05-Jan-14 11:	42.8	42.8	0 43.4	42.7	0 0 05 0.3	0 0.4 0.1 0	2 1	15.3 15.375 15.2 0.2 11.6 8.475 25.5 35.325 31.4 31.65 87.3 34.5 69.8 68.825 8.3 0.825 3.7 0.0 1.2775.5 77 76 76 0 0 4.65 10.2 12.755 34 75 31.65 10.45 4.55 0.835 3.7 0.0 4.679.5 31.0 10.479.5 31.0	12,692.0 167.0 1,706.1 1,023.6 0.0 1,364.9 6 146.0 0.0 642.4 341.3 0.0 642.4
05-Jan-14 1:0	34.4	34.5	0 35.9	34.4	0 0 0.5 0.2	0 0.3 0 0	0 1	12.1 12.05 12 0.1 0 6.825 37.2 37.725 33.5 34.025 80.6 81.125 67.8 66.55 5.4 0.835 3.7 0.0 10.103.5	10,020.0 83.5 1,306.1 682.4 0.0 1,023.6
05-Jan-14 3:0	37.3	37.5	0 18.9	37.2	0 0 0.2 0.2	0 0.3 0.1 0	0 1	6 6.1 6 0.1 13 8.0.5 289 38.0.5 38.3 35.0.5 7.1.3 77.0.5 64.3 65.0.5 -3.5 0.005 3.7 0.0 3,00.0 133 1325 132 0 0 7.325 88 38.175 338 34.405 80.9 81.675 67.5 66.05 6.35 0.805 3.8 0.0 13.005	5,020.0 B3.5 GB2.4 GB2.4 G.D GB2.4 11,022.0 0.0 1,364.9 682.4 0.0 1,023.6
05-lan-14 4:0	52.1	52.2	0 52.2	52.3	0 0 0.9 0.3	0 0.6 0 0	0 1	235 236 225 0 11.5 20.325 341 34.075 20.4 11.6 06.1 04.225 70.2 44.6 4.2 0.015 4.5 0.0 19.6225	19,422.5 0.0 1,070.9 1,023.6 0.0 2,047.3
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05-Jan-14 7:0	60	59.9	0 60	60	0 0 0.8 0.4	0 0.6 0 0	0 1	241 241 241 0 119 11.725 341 34.525 30.3 30.45 86 86.425 70.1 69.8 14.35 0.835 4.1 0.0 20.123.5	20,123.5 0.0 2,729.7 1,364.9 0.0 2,047.3
05-Jan-14 8:0 05-Jan-14 9:0	60	60.1 44.8	0 60	60	0 0 12 0.4	0 0.7 0.1 0	0 1	265 2665 2665 0 0 11.4 11.7 31.2 31.5 20.4 29 86.7 88.925 70.3 70.65 -168.875 0.815 4.5 00 22,210 18.4 38,25 18.3 0 11.5 8.8 34.8 34.8 34.8 34.8 50.9 349.9 561 84.85 67.7 64.85 187.5 0.855 4.5 18.800 22,510.0	22,211.0 0.0 4,094.6 1,364.9 0.0 2,388.5 15,280.5 0.0 2,388.5 1,023.6 0.0 1,706.1
05-Jan-14 10:	60	60	0 60	60	0 0 11 0.4	0 0.7 0.1 0	0 1	26.1 26.275 26.2 0 11.4 11.675 32.9 31.675 27.5 29.625 90.5 67 69.7 64.55 -19.45 0.615 4.5 0.0 21,677.0	21,877.0 0.0 3,753.4 1,364.9 0.0 2,388.5
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06-Jan-14 1:0	60	60	0 60	60	0 0 1.3 0.4	0 0.8 0.1 0	0 1	27.9 27.85 27.9 0 11.7 11.675 32 32.05 28.2 27.25 87.3 99.725 70.9 71.175 19.875 0.885 4.8 0.0 23.296.5	23,256.5 0.0 4,435.8 1,364.9 0.0 2,729.7
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05-Jan-14 4:0	53.2	51.2	0 51.6	53.1	0 0 14 0.3	0 0.8 0 0	0 1	265 263 263 0 0 302 364 31475 204 2675 821 92375 60 72.625 -21.1 0.835 5.2 0.0 22.127.5	22,127.5 0.0 4,777.0 1,023.6 0.0 2,729.7
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06-Jan-14 7:0	60	60	0 60	60	0 0 0.8 0.4	0 0.5 0 0	0 1	22.5 22.425 22.5 0 11.4 11.675 33.2 33.125 29.3 29.325 85.8 85.975 69.7 70.05 20.575 0.885 3.8 218,890.2 18,787.5	18,787.5 0.0 2,729.7 1,364.9 0.0 1,706.1
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06-Jan-14 1:0	41.6	41.7	0 42.4	41.5	0 0 0.5 0.2	0 0.4 0 0	0 1	144 143 142 0.1 11.7 8.2 35.5 34.655 31.7 31.05 85.4 85.2 67.6 69.775 12.3 0.885 3.6 0.0 12.004.0	11,857.0 83.5 1,706.1 682.4 0.0 1,964.9
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06-Jan-14 8:0	48.3	48.3	0 49.1	48.3	0 0 0.6 0.3	0 0.6 0.1 0	0 1	22.1 22.175 22.2 0 11.3 21.725 38.2 31.5 29.3 29.6 86.4 89.955 70.2 70.9 -17.3 0.805 3.9 21,0,072 18,0.03 17.2 37.2 17.2 0.1 11.4 9.6 34.8 31.8 31.1 30.225 83.9 34.675 64.8 49.95 17.8 0.865 3.6 0.0 34.902.0	14,517.0 0.0 2,729.7 1,356.9 0.0 2,047.3 14,362.0 83.5 2,047.3 1,023.6 0.0 1,706.1
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07-Jan-14 1:0	60	60	0 60	60	0 0 1.1 0.4	0 0.7 0 0	0 1	253 25425 253 0 11.7 11.7 32.4 32.3 27.5 27.95 90.4 89.1 70 70.625 18.835 0.885 4.4 0.0 22.125.5	21,125.5 0.0 3,753.4 1,364.9 0.0 2,388.5
07-Jan-14 2:0 07-Jan-14 3:0	60	60	0 60	60	0 0 12 0.4 0 0 12 0.4	0 0.7 0 0	0 1	ana anala ana v 1.6.1 v 1.6.5 v 1.6.5 v 1.6.5 v 1.6.5 v 1.6.5 v 1.8.5 v 1.6.5 v 1.8.5 v 1.6.5 v 1.8.5 v 1.6.5 v 1.8.5	21,793.5 0.0 4,094.6 1,364.9 0.0 2,729.7 21,793.5 0.0 4,094.6 1,364.9 0.0 2,388.5
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07-Jan-147:0	60	60	0 60	60	0 0 0.8 0.4	0 0.6 0.1 0	0 1	222 2225 222 0 11.7 11.725 32.9 12.9 29.1 12.05 862 862 862 70.4 79.3 11.475 0.885 38 218.8860 10.5770	18,537.0 0.0 2,729.7 1,364.9 0.0 2,047.3
07-Jan-14 8:0 07-Jan-14 9:0	60	60 60	0 60	60	0 0 0.9 0.4	0 0.6 0.1 0	0 1	4.89 4.160 4.17 9 1.1.4 11.75 32.7 31.75 20.9 38.75 10.5 10.3 70.7 70.725 -1.0.975 0.005 4.0 0.0 33.766.0 22.2 22.2 22.1 0.1 11.8 11.7 32.8 32.805 19 29 866 46555 70.6 70.6 67.66 4.85 0.855 * *** 0.0 13.55776	18,453.5 83.5 2,388.5 1,364.9 0.0 2,047.3
07-Jan-14 10:	60	60	0 60	60	0 0 0.8 0.4	0 0.6 0 0	0 1	22.2 22.15 22.2 0 11.4 11.725 13 12.9 20.1 29.1 864 86.75 70.9 70.025 -5.455 0.005 14 0.0 145517.0	18,517.0 0.0 2,729.7 1,364.9 0.0 2,047.3
07-Jan-14 11: 07-Jan-14 12:	51.7	39.0	0 52	51.7	0 0 0.7 0.3	0 0.5 0.1 0	0 1	19 38.85 19 0 0 300/5 26.3 33.2 52.6 27.65 79.2 86.825 67.8 7.1.1 -3.46 0.885 5.8 0.0 33.866.0 13.1 31.3 13.1 0.2 11.9 7.925 26.5 14.675 31.4 31.625 85.3 84.3 67.9 64.625 0.025 0.085 3.5 0.0 13.065.5	15,865.0 0.0 2,388.5 1,023.6 0.0 1,706.1 10,918.5 167.0 1,706.1 1,023.6 0.0 1,364.9
07-Jan-14 1:0	30.2	30.3	0 31.2	30.1	0 0 0.4 0.2	0 0.2 0 0	0 1	10.2 9.95 10 0.1 0 5.9 37.8 36.2 33.9 32.615 79.9 83.2 67.5 68.475 0.5 0.885 3.6 0.0 4.517.0	8,350.0 83.5 1,364.9 682.4 0.0 682.4
07-Jan-14 230 07-Jan-14 3:0	35.3	35.3	0 36.2	35.1	0 0 0.4 0.2	0 0.4 0.1 0	0 1	99 20 94 02 114 0.17 30.4 30.9 32.1 33.42 80.1 82.05 00.1 27.55 1.83 0.00 3.5 0.0 2.854 12.4 12.15 12.3 0 0 6.95 36.2 36.6 32.5 32.975 82.4 83 09.2 67.95 2.875 0.885 3.6 0.0 32.554.0	10.270.5 0.0 1.364.9 682.4 0.0 1.364.9
07-Jan-14 4:0	41.9	41.9	0 42.4	42	0 0 0.5 0.1	0 0.4 0 0	0 1	15 15.125 15 0.1 11.4 1.375 349 34.175 30.4 32.5 86.4 41.55 70.5 44.375 2.535 0.005 1.7 0.0 32,525.0	12,525.0 83.5 1,706.1 1,023.6 0.0 1,364.9
07-Jan-14 5:0 07-Jan-14 6:0	4Z.6 50.8	42.6	0 43.9	42.6	0 0 0.5 0.3	0 0.4 0 0	0 1	12.3 12.475 12.52 0.1 11.6 8.4 52.5 32.5 12.675 8.4 83.475 8.1 83.475 8.2 12.52 0.855 3.7 0.0 12,750 0.0 12,75	12,692.0 83.5 1,706.1 1,023.6 0.0 1,364.9 15,698.0 0.0 2,388.5 1,023.6 0.0 1,706.1
07-Jan-14 7:0	53.2	53.1	0 53.5	53.1	0 0 1 0.4	0 0.6 0 0	0 1	238 23.825 238 0 11.6 19.415 32.8 34.45 27.7 39 92.3 87.575 72.4 79.3 5.8 0.835 4.5 0.0 19.873.0	19,873.0 0.0 3,412.1 1,364.9 0.0 2,047.3
07-Jan-14 9:0	60	60	0 60	60	0 0 1 0.4	0 0.6 0 0	0 1	259 258 254 0 12 117 277 1226 269 169 169 169 169 169 169 169 169 169 1	20,040.0 83.5 3,412.1 1,364.9 0.0 2,047.3
07-Jan-14 3D:	60	60	0 60	60	0 0 0.9 0.4	0 0.7 0.1 0	0 1	212 21275 213 0 113 11725 327 31025 29 2905 82 84725 71.4 77.2 12.5 0.825 4.0 0.0 38,372.9	19,455.5 0.0 3,070.9 1,364.9 0.0 2,388.5
09-Jan-14 12:	60	60	0 60	60	0 0 12 0.4	0 0.7 0.1 0	0 1	L5.4 L5.1 L5.4 U 11.7 11.7 32.4 32.7 259 684 893 99.17 72.4 71.0 13.49 0805 4.3 UU 21,042 24.9 24.85 24.85 24.9 0 11.1 11.75 12.3 12.4 12.4 24.8 31.15 88.4 99.475 71.7 71.55 -14.44.55 0.85 4.2 0.0 25.781.5	20,791.5 0.0 1,751.4 1,364.9 0.0 2,388.5
08-Jan-14 1:0	60	60	0 60	60	0 0 11 0.4	0 0.7 0 0	0 1	254 256 256 0 11.9 11.7 32.4 32.4 27.3 28.05 93.6 90.95 72.4 72.075 4.4955 0.885 4.4 0.0 23.36.0	21,376.0 0.0 3,753.4 1,364.9 0.0 2,388.5
08-Jan-14 3:0	47	46.9	0 47.5	47	0 0 0.6 0.3	0 0.4 0.1 0	0 1	181 189 19 0 0 8.175 37.8 4.11 22.8 48.55 76.1 86.5 81.9 66.6 64.25 14.5 0.855 8.5 80.0 13.980.0 13.880.0 13.980.0	13,694.0 167.0 2,047.3 1,023.6 0.0 1,964.9
08-Jan-14 4:0	60	60	0 60	60	0 0 0.7 0.4	0 0.6 0 0	0 1	22.1 22.375 22.4 0 11.4 11.725 33.1 33.25 29.3 29.525 86.4 86.4 69.7 69.475 -0.8175 0.815 3.7 0.0 14.605 5 1.0 10.605 1.0	18,704.0 0.0 2,388.5 1,364.9 0.0 2,047.3
08-Jan-14 6:0	60	60	0 60	60	0 0 0.8 0.4	0 0.6 0 0	0 1	L2.5 L2.6 L2.3 V L1.3 L1.4 L3.3 L3.4 L3	18,527.5 0.0 2,725.7 1,358.5 0.0 2,047.5 18,517.0 0.0 2,725.7 1,368.9 0.0 2,047.3
08-Jan-147-0	60	60	0 60	60	0 0 0.9 0.4	0 0.6 0.1 0	0 1	233 23675 237 0 11.8 11.725 324 328 286 2885 863 86925 663 6495 499 0.835 40 0.0 198730 201 0125 201 0125 214 1125 214 1125 214 1125 214 1125 214 1125 214 1125 214 1125 214 1125 214 1125 214 1125 214	19,789.5 0.0 3,070.9 1,364.9 0.0 2,047.3 21410.5 0.0 4,435.8 1,364.9 1,364.9 3,729.7
08-Jan-14 5:0	60	60	0 60	60	0 0 1.6 0.4	0 0.9 0 0	0 1	289 2905 299 0 11.2 11.40 at. 1.405 263 2637 924 923 137 73.36 40.65 0.855 5.1 0.0 24.965	24,966.5 0.0 5,459.4 1,364.9 0.0 3,070.9
08-Jan-14 10:	60	60	0 60	60	0 0 12 0.4	0 0.8 0.1 0	0 1	26 36 26 0 11.9 11.675 32.1 31.7 26.9 37.3 92.5 99.65 73.6 73.125 -10.55 0.835 4.4 0.0 31.70.0 20.4 31.4 31.4 31.4 31.4 31.4 31.4 31.4 31	21,710.0 0.0 4,094.6 1,364.9 0.0 2,729.7
08-Jan-14 12:	50.2	50.2	0 50.5	50.1	0 0 0.7 0.4	0 0.5 0.1 0	0 î	224 224 224 224 224 22 117 217 217 217 218 225 204 2245 2015 2016 2017 204 2055 204 005 2055 20 00 22,0000 174 1745 1745 173 0.2 113 9425 341 21275 204 29475 194 8415 721 72,025 0.9 0405 3.5 0.0 24,5500	16,744.0 0.0 5,070.5 1,364.9 0.0 1,706.1
08-Jan-14 1:0	35.6	35.5	0 36.7	35.5	0 0 0.5 0.2	0 0.3 0 0	0 1	11.9 11.8 11.7 0.2 12.1 7.05 34.9 35.25 31.4 31.75 88.9 45.55 70.9 70.905 1.775 0.885 3.5 0.0 9.996.5	9,769.5 167.0 1,706.1 682.4 0.0 1,023.6
08-Jan-14 3:0	28.8	28.8	0 29.8	28.7	0 0 0.3 0.2	0 0.2 0 0	0 i	9.3 9.4 9.1 0.2 11.6 5825 562 37.125 32.6 33.6 86.4 82.075 68.5 68.35 69.5 0.855 3.5 0.0 7.7655	7,598.5 167.0 1,023.6 682.4 0.0 682.4
G8-Jan-14 4:0	39.5	39.4	0 40.6	39.6	0 0 05 0.2	0 0.4 0.1 0	0 1	14 341 14 0 11.7 7475 25 34.25 31.2 31.7 874 84.95 71 04.15 5235 04.85 34 0.0 31,650.0 104 149 140 147 141 148 1406 544 35 50.3 31.5 50.2 50 50 50 50 34 35.75 34 50.55 34 50 50 50 50 50 50 50 50 50 50 50 50 50	11,690.0 0.0 1,706.1 682.4 0.0 1,364.9 16.614.6 0.0 1,364.9 16.614.6 0.0 1,266.1
G8-Jan-14 6:0	39.5	39.4	0 39.9	39.5	0 0 05 0.2	0 0.4 0 0	0 î	10.7 10.0 10.7 0.1 11.7 10.0 24.1 33 30.3 11.2 00 01.3 11.7 01.0 01.5 1.4 0.00 10.0 10.0 10.0 10.0 10.0 10.0	11,457.0 167.0 1,706.1 682.4 0.0 1,364.9
08-Jan-147:0	29.2	29.4	0 30.8	29.2	0 0 0.4 0.2	0 0.3 0.1 0	0 1	10.1 20.075 10 0.1 0 3.825 38.8 36.66 34.8 32.975 75.6 81.555 66 64.005 7.3 0.885 3.7 0.0 8.483.5 10.4 34.65 10.4 0 10.2017 10.4 10.5 10.4 10.5 10.4 10.5 10.4 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5	8,350.0 83.5 1,364.9 682.4 0.0 1,023.6
08-Jan-14 9:0	58.2	58.2	0 58.3	58.2	0 0 0.7 0.4	0 0.5 0.1 0	0 1	21.4 21.725 21.6 0 11.7 11.5 38.4 34.425 30 39.675 86.3 48.5 69.8 69 12 0.855 8.8 0.0 34,0856	18/036.0 0.0 2,388.5 1,364.9 0.0 1,706.1
08-Jan-14 10: 08-Jan-14 11:	60	60 60	0 60	60	0 0 0.0 0.4	0 0.6 0 0	0 1	223 2245 224 0 11.4 11.725 314 31.5 29.7 24.725 86.4 86.425 69.7 64.75 4.12.025 0.825 3.8 0.0 18.787.7 233 235 223 0 12 11.725 333 31.4 29.4 24.5 86.3 86.405 69.3 64.75 4.136 0.985 34 71.8860 18.6015	18,704.0 0.0 2,729.7 1,364.9 0.0 2,047.3 18,630.5 0.0 2,729.7 1,364.9 0.0 2,047.3
09-Jan-14 12:	60	60	0 60	60	0 0 0.9 0.4	0 0.6 0.1 0	0 1	217 21.75 23.7 0 11.7 11.725 31.1 11.025 28.2 21.95 90 87.6 69.8 70.1 -15.725 0.815 4.1 0.0 29,789.5	19,789.5 0.0 3,070.9 1,364.9 0.0 2,047.3
09-Jan-14 1:0 09-Jan-14 2:0	60	60 60	0 60	60	0 0 1 0.4	0 0.7 0 0		243 243 243 043 0 11.4 11.75 524 32.75 288 285 87 88.05 70.3 70.5 (1955) 0.855 4.2 0.0 26.751 5 25.1 55.1 0 11.8 11.75 52 32 32.55 28.5 28.1 38.95 71.3 20.75 10.2 0.855 4.2 0.0 28.751	20,751.5 0.0 3,412.1 1,364.9 0.0 2,388.5 20,958.5 0.0 3,753.4 1,364.9 0.0 2,388.5
09-Jan-14 3:0	60	60	0 60	60	0 0 0.9 0.4	0 0.6 0 0	0 1	235 2145 214 0 11.7 11.7 12.4 12.525 20.7 21.575 17.9 10.575 71.2 70.975 -1.1 0.005 4.0 0.0 20,622.5	19,519.0 0.0 3,070.9 1,364.9 0.0 2,047.3
09-Jan-14-4:0 09-Jan-14-5:0	60 50.6	60 50.6	0 60	60 50.7	o 0 0.8 0.4 0 0 0.7 0.1	0 0.6 0.1 0 0 0.5 0 0	0 1	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	18,370.0 0.0 2,729.7 1,364.9 0.0 2,047.3 15,030.0 167.0 2,388.5 1,023.6 0.0 1.706.1
09-Jan-14 6:0	42.3	42.2	0 42.9	42.2	0 0 0.5 0.3	0 0.4 0.1 0	0 1	153 15175 151 0.1 117 8.55 344 347 289 39975 91.9 851 70.5 69.075 5.05 0.885 3.7 0.0 12.775.5	12,608.5 83.5 1,706.1 1,023.6 0.0 1,364.9
09-Jan-14-8:0	50.9	51	0 51.3	50.9	0 0 0.7 0.3	0 0.5 0 0	0 1	18.2 18.2 18.2 19.75 18.2 0.1 11.5 19.75 34.2 33.7 30.5 39.075 88 86.7 71.3 71.45 87.5 08.85 3.6 0.0 15.19.0	15,197.0 83.5 2,388.5 1,023.6 0.0 1,706.1
09-Jan-14 9:0	60	60	0 60	60	0 0 0.8 0.4	0 0.6 0.1 0	0 1	22.2 22.175 22.1 0 11.6 11.75 33.1 31.475 264 29.7 BB7 BB425 72.7 72.425 9.25 0.835 3.8 0.0 34.557.6 10.5 10.5 10.5 10.5 10.5 10.5 10.5 10.5	18,453.5 0.0 2,729.7 1,364.9 0.0 2,047.3
09-lan-14 11:	50.8	50.8	0 51.1	50.7	0 0 0.7 0.1	0 0.5 0.1 0	0 1	LL3 LL425 LL42 0.1 LL5 9. LL45 0.0.1 LL54 9.0 LL54 30.1 20.8 30.475 00.3 0.75 73.2 73.05 LL45 0.05 5.8 2.0 0.0 13.531.0	15,197.0 B3.5 2,388.5 1,023.6 0.0 1,706.1
09-Jan-14 12:	43.6	43.6	0 44.4	43.6	0 0 0.6 0.3	0 0.4 0 0	2 1	152 153 151 0.1 11.6 8.65 34.4 34.75 30.5 31.15 889 88.45 72.3 77.4 16.475 0.885 3.6 0.0 12.690.0	12,608.5 83.5 2,047.3 1,023.6 0.0 1,364.9
09-Jan-14 2:0	41.6	41.7	0 42.7	41.5	0 0 0.6 0.3	0 0.4 0.1 0	0 1	145 14575 145 0.1 11.6 8.125 347 35.625 31 32.025 89.1 85.75 72.6 70.925 20.35 0.835 3.6 0.0 32.07.5	12,107.5 83.5 2,047.3 1,023.6 0.0 1,364.9
09-Jan-14 3:0 09-Jan-14 4:0	30.5	30.5 39.6	0 32.2	30.5	0 0 0.4 0.2	0 0.1 0 0	0 1	9.8 9.675 9.7 0.1 11.8 4.025 36.7 34.475 33 32.95 85 81.725 68 49.875 22.1 0.825 3.5 0.0 8.1810 13.8 31.775 13.6 0.1 12 29.85 85.5 34.675 31.4 20.85 88.7 34.512 21.3 30.65 91.15 4.955 24 4.0 11.552	8,0995 835 1,364.9 682.4 0.0 1,023.6 11,356.0 835 1,306.1 682.4 0.0 5,364.6
09-Jan-14 5:0	39.1	39.2	0 40.7	39.1	0 0 05 03	0 0.4 0 0	0 1	113 11675 1134 61 0 7675 363 361 224 12465 627 62.1 8125 71.1 No.5 1945 045 615 13.7 6.0 11.565	11,523.0 B3.5 1,706.1 1,023.6 0.0 1,364.9
09-Jan-14 6:0 09-Jan-14 7:0	34.8 38.7	34.8	0 35.9	34.8	0 0 0.4 0.2	0 0.3 0.1 0	0 1	12 11.95 12 0.1 12 6.925 52 36.45 336 318 80 81.95 67.4 69.85 19.45 0.885 37 0.0 20,000 133 1135 114 0.1 0 7.45 25.4 36.65 11.9 110 110 110 110 110 110 110 110 110 11	10,020.0 83.5 1,364.9 682.4 0.0 1,023.6 11,189.0 83.5 1,706.1 1,023.6 0.0 1,024.6
09-Jan-14 8:0	30.8	30.9	0 31.7	30.9	0 0 0.4 0.2	0 0.3 0 0	0 1	10.4 10.375 10.3 0.1 11.7 6.15 56.5 36.975 33.4 33.3 82.8 83.225 67.1 69.25 17.9 0.855 3.7 0.0 4.684.0	8,600.5 83.5 1,364.9 682.4 0.0 1,023.6
09-Jan-14 9:0 09-Jan-14 10:	40.3 28.9	40.4 28.8	0 41.1	40.2 28.9	0 0 0.5 0.2 0 0 0.4 0.2	0 0.4 0.1 0	0 1	15 244775 15 0 0 7.9 38.4 34.275 34.4 12.45 76.1 45.125 67.2 44.575 18.025 0.815 3.4 0.0 12.555.0 9.8 9.85 9.6 0.2 12.1 5.8 57.2 37.75 33.5 34.2 85.1 81.2 67.3 47.45 17.575 0.826 3.4 0.0 12.555.0 1.9 1.9 1.9 1.9 1.9 1.9 1.9 1.9 1.9 1.9	12,325.0 0.0 1,706.1 682.4 0.0 1,364.9 8,016.0 167.0 1,364.9 682.4 0.0 1,023.6
09-lan-14 11:	37.4	37.6	0 38.6	37.5	0 0 0.4 0.3	0 0.3 0 0	0 1	114 11425 1144 01 114 7425 181 17 127 113 17 115 01 115 01 144 117475 0105 137 00 112840	11,189.0 83.5 1,364.9 1,023.6 0.0 1,023.6
22-Jan-14 12: 10-Jan-14 1:0	39.7 39.6	39.6	0 40.4	39.6 39.6	o 0 0.5 0.2 0 0 0.5 0.1	0 0.4 0 0 0 0.4 0.1 0	0 1	14.1 34.005 14.2 0.1 11.7 7.85 55.7 34.075 51.9 33 87.7 34.225 70.3 64.6 19.4 0.825 3.7 0.0 11.7735 14.3 14.2 0.1 11.5 7.85 36.7 34.275 32.3 12.6 87 34.425 64.8 64.12 21.4 0.815 3.7 0.0 11.0.015	11,775.5 83.5 1,706.1 682.4 0.0 1,364.9 11,857.0 83.5 1,706.1 1.023.6 0.0 1.364.9
10-Jan-14 2:0	39.7	39.5	0 40.6	39.5	0 0 0.5 0.3	0 0.4 0 0	0 1	141 1405 141 0 11.5 7.8 357 36575 31.9 32.9 87.8 84.2 70.2 68.885 21.925 0.885 3.7 0.0 11.773.5	11,773.5 0.0 1,706.1 1,023.6 0.0 1,364.9
zz-Jan-14 3:0 30-Jan-14 4:0	38.5 22.7	22.5	0 39.4	38.6 22.6	0 0 0.5 0.2	0 0.2 0 0	0 1	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	11,439/5 83.5 1,706.1 682.4 0.0 1,364.9 6,847.0 83.5 1,023.6 682.4 0.0 682.4
10-Jan-14 5:0	34.5	34.6	0 35.7	34.5	0 0 0.4 0.2	0 0.3 0.1 0	0 1	113 11325 11.7 0.1 11.9 0.075 25.3 10.1 224 10.475 07.2 10.9 00.1 07.05 224.05 0.055 14 0.0 0.086.5 14 0.086.5	9,769.5 83.5 1,364.9 682.4 0.0 1,023.6
22-Jan-14 6:0 20-Jan-14 7:0	24.3	24.2 41.9	0.1 25.8 16.5 43.1	24.1 42	v 0 0.3 0.2 0 0 0.8 0.2	v 0.3 0 0 0.6 0.5 0 0	0 1	0.3 0.3 0.2 0.1 0 4.7 40.2 93.225 30.4 34.5 75.4 31.1 65.4 67.2 22.375 0.885 3.7 0.0 6.993.5 17.3 17.125 17.3 0.1 12.7 83.25 37.4 34.5 37.4 32.6 75.8 92.225 07.9 71.375 22.335 0.815 4.1 0.0 14.465.5	0,047.0 85.5 1,025.6 682.4 0.0 1,023.6 14,445.5 83.5 2,729.7 682.4 2,047.3 1,706.1
10-Jan-14 8:0	39.6	39.6	0 40.6	39.6	0 0 0.5 0.3	0 0.4 0 0	0 1	137 13725 136 0.1 119 7.825 965 16.95 32.7 13.275 886 85.075 71.3 63.885 22.5 0.885 3.7 218.890.2 13.493.5	11,356.0 83.5 1,706.1 1,023.6 0.0 1,364.9
20-Jan-14 9:0 30-Jan-14 10:	39.7 34.1	39.6	0 40.3	39.5 34.1	o 0 0.6 0.1 0 0 0.4 0.2	0 0.4 0.1 0 0 0.3 0 0	0 1	14.2 24.175 14.2 0.1 11.5 7.8 36.1 34.85 32.1 31.15 18.9 85.825 72 76.675 22.775 0.815 3.7 0.0 11.0577 12.1 11.8 11.2 0.1 0 6.7 38.2 37.125 34.5 34.4 82.1 85.05 06.8 70.55 24.675 0.825 8.7 0.0 11.057.05	11,773.5 B15 2,047.3 1,021.6 0.0 1,364.9 10,020.0 83.5 1,364.9 682.4 0.0 1.023.6
10-Jan-14 11:	34.4	34.0	0 15.9	34.8	0 0 0.4 0.2	0 0.4 0 0	0 1	11.1 11.775 11.7 0.1 11.4 4975 36.1 17.525 11.1 11.075 07.1 44.25 70.1 64.95 25.115 0.015 1.7 0.0 94.00.0	9,769.5 83.5 1,364.9 682.4 0.0 1,364.9
20-Jan-14 12: 10-Jan-14 1:0	35.1 33.4	35 33.0	0 36.5	35.1	0 0 0.5 0.2 0 0 0.4 0.1	0 0.3 0.1 0 0 0.3 0 0	0 1	LC2 12.4 12.4 0 0 6.9 583 37.375 584 33.575 82.1 85.1 70 N555 26.675 0.885 3.8 0.0 20.475 11.4 11.25 11.1 0.2 12.1 6.75 37.1 37.75 31.3 34.125 88.2 84.25 70.9 68.75 27.85 0.885 3.4 0.0 z0.4875	10,354.0 0.0 1,706.1 682.4 0.0 1,023.6 9,435.5 167.0 1,364.9 1,023.6 0.0 1,023.8
10-Jan-14 2:0	36.2	36.2	0 37.2	36.1	0 0 0.5 0.2	0 0.4 0 0	0 1	12.9 12.7 12.8 0.1 0 7.1 885 37.25 343 39.555 888 85.85 70.7 71.05 28.775 0.885 3.7 0.0 20.771.5	10,688.0 83.5 1,706.1 682.4 0.0 1,364.9
22-Jan-14 3:0 30-Jan-14 4:0	27.9 32.2	27.9 32.1	0 28.0	27.8	0 0 0.4 0.2 0 0 0.4 0.2	0 0.3 0 0	0 1	x1 x1.0 x1 0.1 1.2 5.575 38.2 38.475 34.1 86.5 81.225 66.2 68.675 20.025 68.15 34.6 0.0 7.59815 11.3 11.15 11.3 0.1 0 63.55 39 38.1 38.46 32.8 84.55 70.2 70.25 29 0.855 37 0.0 44.6%	7,431.5 III.5 1,364.9 682.4 0.0 1,023.6 9,435.5 83.5 1,364.9 682.4 0.0 1,023.6
10-Jan-14 5:0	27.9	27.9	0 28.6	27.8	0 0 0.4 0.2	0 0.3 0 0	0 1	9.2 9.2 9.1 0.1 11.7 56 38.2 31.725 34.1 35.1 17.4 19.25 66.7 94.45 20.1 0.825 16 0.0 7,622.0	7,598.5 83.5 1,364.9 682.4 0.0 1,023.6
22-Jan-14 6:0 20-Jan-14 7:0	7.5	7.6	0 7.9	7.5	0 0 0.1 0 0 0 0 0	0 0.1 0 0 0 0 0 0	0 0	3 ε.rrs ε.π 9 U 1.40 40.5 41.23 43.4 33.45 67 75.3 63.8 67.025 29.15 0.835 3.8 0.0 2.505.0 U 0 0 0 0 0 0 51 41.075 41.01 44.55 61.01 41.55 0.23 60.23 0.015 2.5 0.0 0.0	2,421.5 0.0 341.2 0.0 0.0 341.2 0.0 0.0 0.0 0.0 0.0 0.0
10-Jan-14 8:0	11	50.9	0 11.4	11	0 0 0.1 0.1	0 0.1 0 0	0 1	42 42 4 03 127 225 404 473 403 4465 725 607 645 6315 2075 0885 27 00 35070	3,340.0 250.5 341.2 341.2 0.0 341.2
22-381-14 9:0 10-381-14 10:	31.2	31.2	0 32.8	31.5	0 0 0.4 0.2 0 0 0.1 0.1	0 0.1 0 0	0 0	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	3,2565 835 3412 3412 0.0 341.2
10-Jan-14 11:	23.5	23.6	0 24.6	23.5	0 0 03 02	0 0.3 0 0	0 1	85 8.375 8.5 0.1 0 4.675 41.2 1945 17.7 14.05 76.1 49.025 63.4 64.675 11.235 0.815 14 0.0 7.027.5 14 14 14 14 14 14 14 14 14 14 14 14 14 1	7,0975 835 1,0236 682.4 0 0.0 1,023.6
11-Jan-14 1:0	26.8	26.8	0 35	26.8	0 0 0.3 0.2	0 03 0 0	0 1	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	7,598.5 0.0 1,023.6 682.4 0.0 1,023.6
11-Jan-14 2:0	29.2	29.2	0 30.2	29.5	0 0 0.4 0.2	0 03 0 0	2 1	105 1935 104 01 0 5.775 402 38.955 363 151 79.7 83.3 67.4 68.125 31.675 0.885 3.8 0.0 8.77.5 109 11075 109 01 12 4.4 37.5 36.07 34 37.5 mm at at a m	8,684.0 83.5 1,364.9 682.4 0.0 1,023.6
					- 90% Mat	U			



4-variable graphs used to identify heating and cooling seasons



8





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9



COP (heating) = (Energy Delivered + Energy Consumed) / Energy Consumed

COP (cooling) = (Energy Extracted – Energy Consumed) / Energy Consumed



Take-aways:

- 1. Cooling season is short and run time is highly irregular
- 2. Greater loop fluid delta T corresponds to higher COPs
- 3. This system is probably undersized (as are most GSHPs to save install cost)



Take-aways:

- 1. Noticeable decline in COP during the course of a heating or cooling season
 - i. Heating whole system COP 4.5 down to 3.8
 - ii. Cooling whole system COP 10 down to 8
- 2. Addition of loop field pump energy drops heating COP by close to 2 (roughly 6 to 4, for this high-performing system)
- 3. Loop field temperature bottoming out near 32F, peaking at 60F





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Large variability in compressor performance, especially on cooling side.

- i. Variation from each other
- ii. Variation from expected





Large variability in compressor performance, especially on cooling side.

- i. Variation from each other
- ii. Variation from expected

Is the homeowner going to get what they paid for???





Large variability in compressor performance, especially on cooling side.

- i. Variation from each other
- ii. Variation from expected

Welcome to the high-stakes table!







Final measured heating and cooling COPs (compressor + loop pump)

	Heating COP	Cooling COP
Minimum Value	1.51	0.23
25th Percentile	2.88	3.91
Median	3.19	5.20
75th Percentile	3.75	10.13
Maximum Value	7.19	23.44



Final measured heating and cooling COPs (compressor + loop pump)

		Heating COP		Cooling COP	
	Minimum Value		1.51		0.23
"low" COP	25th Percentile		2.88		3.91
"mid" COP	Median		3.19		5.20
"high" COP	75th Percentile		3.75		10.13
	Maximum Value		7.19		23.44

Values used for energy modeling

Michaels Engineering report assumptions: heating COP 3.3, cooling COP 4.1

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9 base cases used to determine GSHP savings in a wide variety of possible installation scenarios

		Home Energy Efficiency				
		Low	Medium	High		
		Pre-energy code	1980's MN energy code	2015 MN energy code		
	2000 sf	1	1	7		
	(small)	1	4			
Home Size	3000 sf (medium)	2	5	8		
	4000 sf (large)	3	6	9		

9 cases x 3 efficiency levels = 27 GSHP models + 9 base cases w fuel-fired GFA + 9 GSHP models w desuperheaters = 45 models total





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Complications:

- 1) Different supply air temperatures meant that fan airflows and therefore fan energy would be different for each system at a given heat load. And REM Rate does not do a good job with fan energy.
- 2) GFA systems are oversized, whereas GSHP systems rely on backup heat systems How much backup? How much oversizing?
- 3) GSHP systems can provide hot water savings with the use of a desuperheater

Fan airflows and energy use based on supply air temperature

Heating equipment	Assumed Supply Air Temp	Source	Resulting fan energy factor
70 AFUE GFA	140°F	CEE, PARR (upper end of range)	0.86
80 AFUE GFA	130°F	CEE, PARR (lower end of range)	1.0 (base case)
90 AFUE GFA	115°F	CEE, PARR (lower end of range)	1.32
GSHP (high, med, low COPs)	95°F	Field data, average heating supply air temp	2.3





Translate site to source energy...

Source energy factors		referenced source
grid electricity	3.15	ANSI Std. 105-2014 (national avg.)
natural gas burned in combustion appliance	1.09	ANSI Std. 105-2014 (national avg.)
LP burned in combustion appliance	1.15	ANSI Std. 105-2014 (national avg.)





Translate site energy to CO2 emissions...

Energy Type	Rate	Units	Source	lbs CO2/MMBtu
electricity	1.82	lbs CO2/kWh	MN PCA	533.4
natural gas	11.79	lbs CO2/therm	US EIA Form EIA-1605 Instructions "Voluntary Reporting of Greenhouse Gases", 2010	117.9
propane	12.55	lbs CO2/gallon	US EIA Form EIA-1605 Instructions "Voluntary Reporting of Greenhouse Gases", 2010	137.4





Translate to energy costs...

Rate assumptions for base case GFA systems (natural gas/propane)

Energy Type	Rate	Units	Time of Year	Source	\$/MMBtu
cooling energy charge	0.15	\$/kWh	June - Sep	2015 MN utility avg. (inc. surcharges)	\$43.96
heating fan energy charge	0.14	\$/kWh	Oct - May	2015 MN utility avg. (inc. surcharges)	\$41.03
nat. gas (water/space heat)	1.00	(\$/therm)	whole year	EIA 5yr avg for MN ('10-'15)	\$10.00
propane (water/space heat)	2.00	(\$/gallon)	whole year	EIA 5yr avg for MN ('10-'15)	\$21.90

Rate assumptions for GSHP systems (all electric)

Energy Type	Rate	Units	Time of Year	Source	\$/MMBtu
cooling energy charge	0.15	\$/kWh	June - Sep	2015 MN utility avg. (inc. surcharges)	\$43.96
heating energy charge	0.10	\$/kWh	Oct - May	2015 MN utility avg. (inc. surcharges)	\$29.31
water heating	0.117	\$/kWh	whole year	(weighted avg. of above)	\$34.19





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Assuming a respectable level of performance (which might be a big if) GSHP can provide certain benefits in cold climates:

- 1) Reduced site energy use for all homes
- 2) Reduced site and source energy use for old, inefficient homes
- 3) For outstate areas, reduced site energy, source energy, CO2 emissions, and energy costs *compared to electric-resistance based systems*
- 4) For outstate areas, reduced and stabilized energy costs *for propane homes*

However, for most new homes in MN, GSHP systems increase source energy use, CO2 emissions, and energy costs.

In mixed-humid climates, results would be substantially different.

ASHP - background

Field research currently underway by Center for Energy and Environment:

Cold Climate Air Source Heat Pump Field Assessment

Team members: Nicole Kessler Josh Quinnell Ben Schoenbauer

Will install and monitor performance of 6-8 air source heat pumps in a variety of installation conditions www.mncee.org/heat_pumps

2 ductless models, 6 ducted



College of Design UNIVERSITY OF MINNESOTA

ASHP - background

Several complicating factors with ASHP efficiency:

- 1. COP varies considerably with temperature
- 2. In cold climates, COP impacted by backup heat
- 3. And defrost cycles





ASHP Performance – Preliminary Data



- Rated COPs of 3.0-3.5 at 47 F
- COP observed
 - 1.5-3.5 (site 1 & 2)
 - 1-3.5 (site 3)
- 2015-2016 heating season
- Results shown with no backup, no frostprotection









Preliminary Results



Center for Energy and Environment

Including impact of backup heat reduces the combined COP







Eventually, COP approaches furnace efficiency

Energy Use and Costs

- Assumptions:
 - 40,000 Btu/hr design heating load
 - Minneapolis TMY3
 - Equipment specifications

			LP Use	Electric Use	Annual Cost
	Avg COP	%ASHP	therms/yr	kWh/yr	\$/yr
Propane Furnace	0.80	0%	876	0	\$1,732
Propane Furnace	0.95	0%	735	0	\$1,453
ASHP w/30°F Change-over	1.18	27%	528	1,898	\$1,272
ASHP w/10°F Change-over	1.81	79%	152	6,859	\$1,124
ASHP w/0°F Change-over	1.97	89%	84	7,958	\$1,120



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ASHP w/10°F Change-over	1.81	79%	152	6,859	\$1,124	2.38
ASHP w/0°F Change-over	1.97	89%	84	7,958	\$1,120	2.27

			· · · · · · · · · · · · · · · · · · ·			-
ASHP w/0°F, electric backup	2.17	89%	0	2590 + 7958	\$1,266	2.27

ASHP COP declines as it spends more time operating at cold temperatures, but... Avg. COP of total system goes up as backup use goes down.

Comparison and Discussion

How do GSHP and ASHP systems compare, and what are their implications for code houses and Passive Houses? Assume GFA-based code house is "base case"

- 1. GSHP definitely provides highest efficiency
- Both ASHP and GSHP will reduce *site* energy substantially

	heating	cooling
	СОР	СОР
GFA (base case)	0.90	3.4
GSHP (mid efficiency)	3.2	5.2
ASHP (ducted, w resistance backup and 0°F switchover)	2.2	4

Comparison and Discussion

How do GSHP and ASHP systems compare, and what are their implications for code houses and Passive Houses? Assume GFA-based code house is "base case"

- Compared to base case, GSHP and ASHP increase source energy slightly.
- Compared to base case, PHIUS+ saves roughly 55% (6200 kWh x (bed + 1))



Comparison and Discussion

How do GSHP and ASHP systems compare, and what are their implications for code houses and Passive Houses? Assume GFA-based code house is "base case"

- Compared to base case, GSHP and ASHP increase emissions significantly.
- Compared to base case, PHIUS+ saves 45% (assuming all site energy is electric, which is worst case)



We know the primary energy requirement is very tight. Maybe be the toughest requirement to hit without resorting to renewables. How do these systems stack up in terms of primary energy use?

Annual load x PE factor/efficiency = primary energy

Base case: GFA system with 95AFUE, PE factor 1.09 1.09/0.95 = **1.15**

This is the ratio to beat. A lower number saves primary energy.



We know the primary energy requirement is very tight. Maybe be the toughest requirement to hit without resorting to renewables. How do these systems stack up in terms of primary energy use?

Annual load x PE factor/efficiency = primary energy

GSHP system: Heating COP 3.2, PE factor 3.16 3.16/3.2 = **0.99**

GSHP system will help reduce primary energy use for space heating.



We know the primary energy requirement is very tight. Maybe be the toughest requirement to hit without resorting to renewables. How do these systems stack up in terms of primary energy use?

Annual load x PE factor/efficiency = primary energy

Ducted ASHP system: Heating COP 2.2 (w 10% electric resistance backup), PE factor 3.16 3.16/2.2 = **1.44**

ASHP system in very cold climates will increase primary energy use for space heating.



We know the primary energy requirement is very tight. Maybe be the toughest requirement to hit without resorting to renewables. How do these systems stack up in terms of primary energy use?

Annual load x PE factor/efficiency = primary energy

Ducted ASHP system: Heating COP 2.8 (w 10% electric resistance backup), PE factor 3.16 3.16/2.8 = **1.13**

ASHP systems must achieve COP of 2.8 (including backup heating) to reduce primary energy use for space heating.



We know the primary energy requirement is very tight. Maybe be the toughest requirement to hit without resorting to renewables. How do these systems stack up in terms of primary energy use?

Annual load x PE factor/efficiency = primary energy

Ducted ASHP system: Heating COP 2.8 (w 10% electric resistance backup), PE factor 3.16 3.16/2.8 = **1.13**

ASHP systems must achieve COP of 2.8 (including backup heating) to reduce primary energy compared to base case.

Data from CEE's monitoring on ducted cold climate ASHP suggests this may not be possible (yet) in Minnesota, or similar climate zone 6

ASHP Performance – Preliminary Data



- Rated COPs of 3.0-3.5 at 47 F
- COP observed
 - 1.5-3.5 (site 1 & 2)
 - 1-3.5 (site 3)
- 2015-2016 heating season
- Results shown with no backup, no frostprotection



ASHP Performance – Preliminary Data



And remember that with a Passive House, the balance point is shifted lower and The vast majority of heating load will be at temperatures below 50F

3 home sizes

2000 sf house	3000 sf house	4000 sf house
26' x 26'	31.5' x 31.5'	36.5' x 36.5'
3-bed, 2-story with conditioned basement	4-bed, 2-story with conditioned basement	5-bed, 2-story with conditioned basement
0.15 window to floor area ratio 300 sf window area equally distributed	0.15 window to floor area ratio 450 sf window area equally distributed	0.15 window to floor area ratio 600 sf window area equally distributed

High efficiency (2015 MN Energy Code)	Values	Notes
Ceiling R-value	50.0	2015 MN Energy Code
Wall R-value	21.0	2015 MN Energy Code
Rim joist R-value	21.0	same as wall
Basement Wall R-value	15.0	2015 MN Energy Code
Slab R-value	10.0	2015 MN Energy Code
Fenestration U-factor (area-weighted avg.)	0.32	2015 MN Energy Code
Fenestration SHGC (area-weighted avg.)	0.26	approx. industry average
Airtightness (ACH@50Pa)	3.0	2015 MN Energy Code
Window-to-Floor Area Ratio	0.15	2012 IECC max
Furnace AFUE	90	2012 IECC
Air Conditioner SEER	13.0	2012 IECC
DHW ER	0.62	2012 IECC, 2015 NAECA
Ventilation Rate (cfm, continuous)	55/75/95	2015 MN Energy Code (2000/3000/4000sf)
Sensible Recovery Efficiency (%)	60.0	HRV (w separate kitchen fan)
Duct location		conditioned space
Lighting CFL percentage	80%	

3 home efficiency levels

"High efficiency" = 2015 MN energy code

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Med. efficiency (1980's MN Energy Code)	Values	Notes
Ceiling R-value	38.0	
Wall R-value	19.0	
Rim joist R-value	13.0	
Basement Wall R-value	10.0	
Slab R-value	10.0	
Fenestration U-factor (area-weighted avg.)	0.46	double clear vinyl (REM Rate library)
Fenestration SHGC (area-weighted avg.)	0.57	double clear vinyl (REM Rate library)
Airtightness (ACH@50Pa)	5,4,3	(est. rates 2000sf, 3000sf, 4000sf)
Window-to-Floor Area Ratio	0.15	
Furnace AFUE	80	
Air Conditioner SEER	10.0	
DHW ER	0.56	
Ventilation Rate (cfm, runtime)	50, 3/4/5hr	exhaust only (2000/3000/4000sf)
Sensible Recovery Efficiency (%)	0.0	no recovery
Duct location		conditioned space
Lighting CFL percentage	50%	

3 home efficiency levels

"Med. efficiency" = 1980's MN energy code

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TSP!

Low efficiency (Pre-Energy Code)	Values	Notes]
Ceiling R-value	24.0	7 inches cellulose	
Wall R-value	11.0	insulated 2x4 wall	
Rim joist R-value	11.0	same as wall	
Basement Wall R-value	5.0	1 inch interior foam board	
Slab R-value	0.0	carpeted slab]
Fenestration U-factor (area-weighted avg.)	0.67	single wood frame w storm (REM Rate lib.)	
Fenestration SHGC (area-weighted avg.)	0.65	single wood frame w storm (REM Rate lib.)	
Airtightness (ACH@50Pa)	7,6,5	(est. rates 2000sf, 3000sf, 4000sf)]
Window-to-Floor Area Ratio	0.15	same as other models	
]
Furnace AFUE	70	Gas Furn Pre 1987 (REM Rate library)	1
Air Conditioner SEER	9.0	Cent AC Pre 1987 (REM Rate library)	
DHW ER	0.55	Gas Stor 1984-87 (REM Rate library)	
Ventilation Rate (cfm, runtime)	50, 3/4/5hr	exhaust only (2000/3000/4000sf)	
Sensible Recovery Efficiency (%)	0.0	no recovery]
Duct location		conditioned space	
]
Lighting CFL percentage	50%		

3 home efficiency levels

"Low efficiency" = Pre-energy code with some insulation retrofit

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