Performance, Emissions, Economic Analysis of Minnesota Geothermal Heat Pumps

Final Report

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Executive Summary

The primary purpose of this project was to

- Determine the difference in energy consumption, user costs, and amounts of pollutants and carbon dioxide emissions for Ground Source Heat Pumps (GHPs) as compared to conventional Heating, Ventilation and Air Conditioning (HVAC) systems in Minnesota residential, commercial and institutional buildings used for heating and cooling air and water heating, and;
- Identify current installations of GHPs, available financial incentives, manufacturers and installers, economic development potential, and barriers to more widespread, cost effective use of the technology in Minnesota.

The scope of this analysis allowed for a thorough review of best available data and studies to develop representative rated capacity and performance of equipment. Although much of the data and information used in these studies came from site-specific evaluations, the scope of this project did not allow for independent collection of data from individual systems operating in Minnesota.

Given that energy performance of heating and cooling systems in buildings and resultant emissions are highly dependant on the assumptions used, caution is urged in applying results to performance of an individual system. A detailed literature review of case studies and research was conducted, and recently published research and evaluation studies were used to determine the assumptions used. The project's comprehensive analysis resulting from use of these assumptions represents a fair and reasonable comparison of systems.

Summary of Results

The first primary task of this study was to determine the difference in energy consumption, user costs, and amounts of pollutants and carbon dioxide emissions for GHPs as compared to conventional HVAC systems in Minnesota residential, commercial and institutional buildings used for heating and cooling air and water heating. Building models were constructed in DOE2 for three Minnesota climate zones for the categories of commercial, institutional, and residential buildings. In each scenario, the monthly and annual electric energy consumption, electric demand, and natural gas consumption values were determined for both the conventional HVAC system and a GHP HVAC system. Energy results were used to determine the economic and emissions results for each case. All GHP systems modeled have rated cooling and heating efficiencies of 14.1 EER and 3.3 COP, respectively. Some GHP systems were also modeled with a desuperheater, which decreased annual energy costs, life-cycle costs, and annual emissions in every case in which it was applied. Results with the desuperheater option are shown in the main body of the report.

Commercial Results

Commercial buildings were analyzed using building models for small and large office buildings. The small office conventional system is a relatively inexpensive packaged VAV system with cooling and heating efficiencies of 12.0 EER and 80%, respectively provided from the packaged rooftop unit and zone heating provided by an 80% efficient gas heater in each space. The large office conventional system is a VAV system with a water-cooled chiller with a 16.7 EER and a boiler with 85% rated efficiency for the cooling and heating, respectively. The comparisons between these systems and the GHP systems are detailed below.

Small Office, New Construction

The small office new construction building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The small office new construction building with the GHP HVAC system had higher electrical costs than the conventional HVAC system but no natural gas costs associated. The annual savings from the GHP installation provided a net increase in life cycle costs. The installation of a GHP system in a small office new construction building reduces CO2 equivalent greenhouse gas (GHG) emissions approximately 10-13%, but increases emissions of SO2, PM and Hg due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 1 through Table 3.

Table 1: Annual Demand and Energy Values for a Small Office New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	55	138,340	7,413	51	167,125	0	4	-28,785	7,413
St. Cloud	54	143,369	6,540	51	168,733	0	3	-25,364	6,540
Minneapolis	55	145,332	6,260	51	169,434	0	4	-24,102	6,260

Table 2: Economics of Conventional and GHP HVAC Systems for a Small Office New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 208,096	$ 3,473	$ 16,882	$ 416,536	$ 370,671	$ 3,395	$ 11,666	$ 443,602	$ 5,294	30.7	$ (27,066)	-6.5%
St. Cloud	$ 208,096	$ 3,473	$ 16,374	$ 412,039	$ 370,671	$ 3,395	$ 11,815	$ 445,391	$ 4,637	35.1	$ (33,352)	-8.1%
Minneapolis	$ 208,096	$ 3,473	$ 16,113	$ 409,424	$ 370,671	$ 3,395	$ 11,581	$ 442,584	$ 4,610	35.4	$ (33,160)	-8.1%

Table 3: Annual Emissions Values for a Small Office New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	317,172	616	576	112	0.0063	318,353
	GHP	277,809	743	614	129	0.0074	278,664
	Reduction	39,363	-128	-37	-17	-0.0011	39,689
	% Change	-12.4%	20.7%	6.5%	14.9%	17.2%	-12.5%
St. Cloud	Conventional	315,261	638	587	115	0.0065	316,412
	GHP	280,482	750	620	130	0.0074	281,345
	Reduction	34,779	-112	-33	-15	-0.0009	35,067
	% Change	-11.0%	17.6%	5.6%	12.7%	14.7%	-11.1%
Minneapolis	Conventional	315,230	647	591	117	0.0066	316,373
	GHP	281,647	754	622	131	0.0075	282,514
	Reduction	33,583	-107	-31	-14	-0.0009	33,859
	% Change	-10.7%	16.5%	5.2%	11.9%	13.7%	-10.7%

* CO2 (carbon dioxide), SO2 (sulfur dioxide), NOx (Nitrogen Oxide) PM (Particulate Matter), CO2 Eq. (equivalent CO2 greenhouse effect by combining the affects of CO2 and N2O emissions).

Small Office, Existing Building

The small office existing building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The small office existing building with the GHP HVAC system had higher electrical costs than the conventional HVAC system but no natural gas costs associated. The annual savings from the installation provided a net increase in life cycle costs. The installation of a GHP system in a small office existing building reduces CO2 equivalent GHG emissions 15-17%, but SO2, PM and Hg emissions increase due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 4 through Table 6.

Table 4: Annual Demand and Energy Values for a Small Office Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	68	170,395	10,723	64	204,576	0	4	-34,181	10,723
St. Cloud	71	182,051	9,098	66	209,463	0	5	-27,412	9,098
Minneapolis	71	184,512	8,881	66	210,829	0	5	-26,317	8,881

Table 5: Economics of Conventional and GHP HVAC Systems for a Small Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 221,102	$ 3,473	$ 22,335	$ 489,519	$ 409,689	$ 3,395	$ 14,204	$ 513,047	$ 8,209	23.0	$ (23,528)	-4.8%
St. Cloud	$ 221,102	$ 3,473	$ 21,558	$ 483,170	$ 409,689	$ 3,395	$ 14,617	$ 517,995	$ 7,019	26.9	$ (34,825)	-7.2%
Minneapolis	$ 221,102	$ 3,473	$ 21,350	$ 481,083	$ 409,689	$ 3,395	$ 14,364	$ 514,963	$ 7,064	26.7	$ (33,880)	-7.0%

Table 6: Annual Emissions Values for a Small Office Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	409,398	758	725	139	0.0078	410,954
	GHP	340,063	910	751	158	0.0090	341,109
	Reduction	69,334	-151	-27	-18	-0.0012	69,844
	% Change	-16.9%	20.0%	3.7%	13.2%	15.8%	-17.0%
St. Cloud	Conventional	409,655	810	752	147	0.0082	411,167
	GHP	348,187	932	769	162	0.0092	349,258
	Reduction	61,469	-121	-17	-14	-0.0010	61,909
	% Change	-15.0%	15.0%	2.2%	9.8%	11.8%	-15.1%
Minneapolis	Conventional	411,193	821	759	149	0.0083	412,704
	GHP	350,457	938	774	163	0.0093	351,536
	Reduction	60,736	-117	-15	-14	-0.0009	61,168
	% Change	-14.8%	14.2%	1.9%	9.2%	11.2%	-14.8%

Large Office, New Construction

The large office new construction building with the GHP HVAC system had higher summer and winter electrical demand and electrical energy consumption values than the conventional HVAC system. The large office new construction building with the GHP HVAC system had higher electrical costs but lower natural gas costs than the conventional HVAC system. The annual savings from the installation provided a net decrease in life cycle costs. The installation of a GHP system in a large office new construction building decreases CO2 equivalent GHG emissions approximately 3-4%, but SO2, PM and Hg emissions increase due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 7 through Table 9.

Table 7: Annual Demand and Energy Values for a Large Office New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	273	713,143	28,761	291	864,490	1,920	-18	-151,347	26,841
St. Cloud	278	754,653	25,212	295	886,603	1,812	-17	-131,950	23,400
Minneapolis	286	765,248	24,638	302	896,950	1,728	-16	-131,702	22,910

Table 8: Economics of Conventional and GHP HVAC Systems for a Large Office New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 1,801,440	$ 11,109	$ 74,216	$ 2,382,494	$ 2,139,210	$ 8,932	$ 56,507	$ 2,300,844	$ 19,886	17.0	$ 81,650	3.4%
St. Cloud	$ 1,801,440	$ 11,109	$ 73,498	$ 2,380,375	$ 2,139,210	$ 8,932	$ 58,025	$ 2,319,233	$ 17,650	19.2	$ 61,142	2.6%
Minneapolis	$ 1,801,440	$ 11,109	$ 75,141	$ 2,401,119	$ 2,139,210	$ 8,932	$ 60,191	$ 2,345,347	$ 17,127	19.7	$ 55,772	2.3%

Table 9: Annual Emissions Values for a Large Office New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,523,810	3,173	2,901	571	0.0321	1,529,293
	GHP	1,459,615	3,845	3,194	668	0.0381	1,464,159
	Reduction	64,195	-671	-293	-97	-0.0060	65,135
	% Change	-4.2%	21.2%	10.1%	16.9%	18.6%	-4.3%
St. Cloud	Conventional	1,551,058	3,358	3,019	601	0.0338	1,556,527
	GHP	1,495,102	3,943	3,274	685	0.0391	1,499,752
	Reduction	55,956	-585	-255	-84	-0.0052	56,775
	% Change	-3.6%	17.4%	8.5%	14.0%	15.4%	-3.6%
Minneapolis	Conventional	1,561,917	3,405	3,052	609	0.0343	1,567,404
	GHP	1,511,313	3,989	3,311	693	0.0395	1,516,011
	Reduction	50,604	-584	-259	-84	-0.0052	51,393
	% Change	-3.2%	17.2%	8.5%	13.9%	15.2%	-3.3%

Large Office, Existing Building

The large office existing building with the GHP HVAC system had higher summer and winter electrical demand and electrical energy consumption values than the conventional HVAC system. The large office existing building with the GHP HVAC system had higher electrical costs but lower natural gas costs than the conventional HVAC system. The annual savings from the installation provided a net increase in life cycle costs. The installation of a GHP system in a large office existing building decreases equivalent GHG emissions by approximately 4-5%, and increases SOx, PM and Hg emissions increase due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 10 through Table 12.

Table 10: Annual Demand and Energy Values for a Large Office Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	350	902,099	38,064	374	1,093,608	1,920	-24	-191,509	36,144
St. Cloud	360	954,552	31,396	384	1,118,840	1,812	-24	-164,288	29,584
Minneapolis	365	967,632	31,895	386	1,130,397	1,728	-21	-162,765	30,167

Table 11: Economics of Conventional and GHP HVAC Systems for a Large Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 1,876,500	$ 11,109	$ 95,518	$ 2,695,863	$ 2,364,390	$ 8,932	$ 71,078	$ 2,700,676	$ 26,617	18.3	$ (4,813)	-0.2%
St. Cloud	$ 1,876,500	$ 11,109	$ 92,494	$ 2,671,806	$ 2,364,390	$ 8,932	$ 72,914	$ 2,722,880	$ 21,756	22.4	$ (51,075)	-1.9%
Minneapolis	$ 1,876,500	$ 11,109	$ 95,810	$ 2,710,646	$ 2,364,390	$ 8,932	$ 75,607	$ 2,755,307	$ 22,380	21.8	$ (44,660)	-1.6%

Table 12: Annual Emissions Values for a Large Office Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,947,355	4,014	3,686	724	0.0407	1,954,399
	GHP	1,840,473	4,864	4,035	845	0.0482	1,846,189
	Reduction	106,882	-850	-349	-121	-0.0075	108,210
	% Change	-5.5%	21.2%	9.5%	16.7%	18.5%	-5.5%
St. Cloud	Conventional	1,956,099	4,247	3,813	760	0.0428	1,962,986
	GHP	1,881,145	4,976	4,127	864	0.0493	1,886,984
	Reduction	74,954	-729	-313	-105	-0.0065	76,002
	% Change	-3.8%	17.2%	8.2%	13.8%	15.1%	-3.9%
Minneapolis	Conventional	1,983,713	4,305	3,866	770	0.0434	1,990,698
	GHP	1,899,368	5,027	4,168	873	0.0498	1,905,260
	Reduction	84,345	-722	-302	-103	-0.0064	85,438
	% Change	-4.3%	16.8%	7.8%	13.4%	14.7%	-4.3%

Institutional Results

Institutional buildings were analyzed using building models for small and large schools. The small school conventional system is a VAV system with an air-cooled chiller with a 12.0 EER and a boiler with 85% rated efficiency for the cooling and heating, respectively. The large school conventional system is a VAV system with a water-cooled chiller with a 20.8 EER and a boiler with 85% rated efficiency for the cooling and heating, respectively. The comparisons between these systems and the GHP systems are detailed below.

Small School, New Construction

The small school new construction building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The small school new construction building with the GHP HVAC system had higher electrical costs but lower natural gas costs than the conventional HVAC system. The annual savings from the installation provided a net decrease in life cycle costs. The installation of a GHP system in a small school new construction building reduces CO2 equivalent GHG emissions approximately 11-13%, but SOx, PM and Hg emissions increase due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 13 through Table 15.

Table 13: Annual Demand and Energy Values for a Small School New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	167	416,169	29,617	164	473,843	9,737	3	-57,674	19,880
St. Cloud	180	436,106	26,491	175	476,223	9,175	5	-40,117	17,316
Minneapolis	187	446,072	25,423	181	497,547	8,726	6	-51,475	16,697

Table 14: Economics of Conventional and GHP HVAC Systems for a Small School New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 1,658,736	$ 20,306	$ 59,193	$ 2,201,302	$ 1,969,749	$ 16,104	$ 43,956	$ 2,101,371	$ 19,439	16.0	$ 99,931	4.5%
St. Cloud	$ 1,658,736	$ 20,306	$ 57,711	$ 2,189,247	$ 1,969,749	$ 16,104	$ 43,826	$ 2,100,831	$ 18,087	17.2	$ 88,416	4.0%
Minneapolis	$ 1,658,736	$ 20,306	$ 58,913	$ 2,205,607	$ 1,969,749	$ 16,104	$ 46,458	$ 2,133,207	$ 16,656	18.7	$ 72,400	3.3%

Table 15: Annual Emissions Values for a Small School New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,040,226	1,853	1,819	343	0.0191	1,044,245
	GHP	902,214	2,108	1,836	373	0.0211	905,259
	Reduction	138,012	-255	-17	-30	-0.0020	138,986
	% Change	-13.3%	13.8%	0.9%	8.6%	10.7%	-13.3%
St. Cloud	Conventional	1,036,590	1,941	1,861	356	0.0199	1,040,512
	GHP	899,558	2,118	1,839	374	0.0212	902,580
	Reduction	137,032	-177	22	-18	-0.0013	137,932
	% Change	-13.2%	9.1%	-1.2%	5.1%	6.7%	-13.3%
Minneapolis	Conventional	1,040,592	1,985	1,887	363	0.0203	1,044,496
	GHP	929,722	2,213	1,913	390	0.0221	932,824
	Reduction	110,869	-228	-25	-27	-0.0018	111,672
	% Change	-10.7%	11.5%	1.3%	7.5%	9.1%	-10.7%

Small School, Existing Building

The small school existing building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The small school existing building with the GHP HVAC system had higher electrical costs but lower natural gas costs than the conventional HVAC system. The annual savings from the installation provided a net decrease in life cycle costs. The installation of a GHP system in a small school existing building reduces CO2 equivalent GHG emissions around 10-13%, but SOx, PM and Hg, emissions increase due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 16 through Table 18.

Table 16: Annual Demand and Energy Values for a Small School Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	201	516,434	34,989	198	593,181	9,737	3	-76,747	25,252
St. Cloud	216	538,793	29,077	211	586,148	9,175	5	-47,355	19,902
Minneapolis	221	550,976	28,759	215	614,149	8,726	6	-63,173	20,033

Table 17: Economics of Conventional and GHP HVAC Systems for a Small School Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 2,004,306	$ 20,306	$ 71,475	$ 2,684,254	$ 2,315,319	$ 16,104	$ 52,336	$ 2,547,384	$ 23,341	13.3	$ 136,870	5.1%
St. Cloud	$ 2,004,306	$ 20,306	$ 67,496	$ 2,647,376	$ 2,315,319	$ 16,104	$ 51,483	$ 2,538,188	$ 20,215	15.4	$ 109,188	4.1%
Minneapolis	$ 2,004,306	$ 20,306	$ 69,875	$ 2,676,470	$ 2,315,319	$ 16,104	$ 54,772	$ 2,578,424	$ 19,305	16.1	$ 98,045	3.7%

Table 18: Annual Emissions Values for a Small School Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,270,094	2,299	2,240	424	0.0236	1,274,970
	GHP	1,100,587	2,639	2,274	465	0.0263	1,104,243
	Reduction	169,507	-340	-34	-40	-0.0027	170,727
	% Change	-13.3%	14.8%	1.5%	9.5%	11.6%	-13.4%
St. Cloud	Conventional	1,237,708	2,398	2,264	437	0.0244	1,242,320
	GHP	1,082,285	2,607	2,242	459	0.0260	1,085,868
	Reduction	155,424	-209	21	-22	-0.0016	156,452
	% Change	-12.6%	8.7%	-0.9%	5.0%	6.4%	-12.6%
Minneapolis	Conventional	1,254,219	2,452	2,305	446	0.0250	1,258,873
	GHP	1,123,548	2,732	2,341	480	0.0272	1,127,246
	Reduction	130,671	-280	-36	-34	-0.0023	131,627
	% Change	-10.4%	11.4%	1.5%	7.6%	9.1%	-10.5%

Large School, New Construction

The large school new construction building with the GHP HVAC system had higher summer and winter electrical demand and electrical energy consumption values than the conventional HVAC system. The large school new construction building with the GHP HVAC system had higher electrical costs but lower natural gas costs than the conventional HVAC system. The annual savings from the installation provided a net decrease in life cycle costs. The installation of a GHP system in a large school new construction building reduces CO2 equivalent GHG emissions around 3-8%, but SOx, PM, and Hg, emissions increase due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 19 through Table 21.

Table 19: Annual Demand and Energy Values for a Large School New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	774	2,284,108	222,536	920	2,845,109	98,487	-146	-561,001	124,049
St. Cloud	829	2,387,581	200,758	994	2,872,144	92,804	-165	-484,563	107,954
Minneapolis	855	2,428,273	194,870	1,028	3,048,907	88,257	-173	-620,634	106,613

Table 20: Economics of Conventional and GHP HVAC Systems for a Large School New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 9,271,872	$ 39,405	$ 377,526	$ 11,855,476	$ 11,010,348	$ 31,251	$ 296,568	$ 11,571,409	$ 89,113	19.6	$ 284,067	2.4%
St. Cloud	$ 9,271,872	$ 39,405	$ 364,082	$ 11,734,169	$ 11,010,348	$ 31,251	$ 296,898	$ 11,585,764	$ 75,338	23.3	$ 148,405	1.3%
Minneapolis	$ 9,271,872	$ 39,405	$ 368,238	$ 11,794,763	$ 11,010,348	$ 31,251	$ 311,748	$ 11,772,075	$ 64,645	27.1	$ 22,688	0.2%

Table 21: Annual Emissions Values for a Large School New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	6,414,903	10,171	10,570	1,927	0.1062	6,440,792
	GHP	5,888,044	12,658	11,414	2,268	0.1277	5,908,884
	Reduction	526,858	-2,488	-844	-340	-0.0215	531,908
	% Change	-8.2%	24.5%	8.0%	17.7%	20.3%	-8.3%
St. Cloud	Conventional	6,330,692	10,630	10,736	1,991	0.1102	6,355,721
	GHP	5,866,125	12,778	11,457	2,284	0.1287	5,886,741
	Reduction	464,567	-2,149	-721	-293	-0.0186	468,980
	% Change	-7.3%	20.2%	6.7%	14.7%	16.9%	-7.4%
Minneapolis	Conventional	6,329,063	10,810	10,828	2,018	0.1118	6,353,924
	GHP	6,106,461	13,564	12,062	2,417	0.1364	6,127,690
	Reduction	222,602	-2,754	-1,234	-399	-0.0246	226,234
	% Change	-3.5%	25.5%	11.4%	19.8%	22.0%	-3.6%

Large School, Existing Building

The large school existing building with the GHP HVAC system had higher summer and winter electrical demand and electrical energy consumption values than the conventional HVAC system. The large school existing building with the GHP HVAC system had higher electrical costs but lower natural gas costs than the conventional HVAC system. The annual savings from the installation provided a net decrease in life cycle costs. The installation of a GHP system in a large school existing building reduces CO2 equivalent GHG emissions around 5-9%, but SOx, PM, and Hg emissions increase due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 22 through Table 24.

Table 22: Annual Demand and Energy Values for a Large School Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	926	2,896,605	281,242	1,045	3,764,656	98,487	-119	-868,051	182,755
St. Cloud	982	3,035,195	240,152	1,117	3,721,404	92,804	-135	-686,209	147,348
Minneapolis	1,039	3,090,630	237,229	1,195	3,923,150	88,257	-156	-832,520	148,972

Table 23: Economics of Conventional and GHP HVAC Systems for a Large School Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 11,203,512	$ 39,405	$ 475,877	$ 14,858,555	$ 12,941,988	$ 31,251	$ 357,684	$ 14,235,588	$ 126,348	13.8	$ 622,967	4.2%
St. Cloud	$ 11,203,512	$ 39,405	$ 445,995	$ 14,575,552	$ 12,941,988	$ 31,251	$ 353,425	$ 14,194,937	$ 100,724	17.4	$ 380,615	2.6%
Minneapolis	$ 11,203,512	$ 39,405	$ 455,516	$ 14,695,019	$ 12,941,988	$ 31,251	$ 372,000	$ 14,425,898	$ 91,670	19.1	$ 269,121	1.8%

Table 24: Annual Emissions Values for a Large School Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	8,123,704	12,898	13,395	2,443	0.1346	8,156,475
	GHP	7,416,591	16,748	14,791	2,977	0.1682	7,442,134
	Reduction	707,113	-3,850	-1,396	-533	-0.0335	714,341
	% Change	-8.7%	29.8%	10.4%	21.8%	24.9%	-8.8%
St. Cloud	Conventional	7,870,668	13,512	13,501	2,520	0.1397	7,901,524
	GHP	7,277,835	16,555	14,576	2,939	0.1661	7,302,794
	Reduction	592,833	-3,043	-1,075	-419	-0.0264	598,730
	% Change	-7.5%	22.5%	8.0%	16.6%	18.9%	-7.6%
Minneapolis	Conventional	7,928,428	13,759	13,676	2,560	0.1420	7,959,382
	GHP	7,559,700	17,452	15,272	3,091	0.1749	7,585,400
	Reduction	368,729	-3,694	-1,597	-531	-0.0328	373,981
	% Change	-4.7%	26.8%	11.7%	20.7%	23.1%	-4.7%

Residential Results

Residential buildings were analyzed using building models for small and large houses. The small and large house conventional systems are split system air conditioners with a 14 SEER with 92% rated high-efficiency furnaces for the cooling and heating, respectively. The comparisons between these and the GHP systems are detailed below.

Small House, New Construction

The small house new construction building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The small house new construction building with the GHP HVAC system had higher electrical costs than the conventional HVAC system but no natural gas costs. The annual savings from the installation provided a net increase in life cycle costs. The installation of a GHP system in a small house new construction building increases CO2 equivalent GHG emissions approximately 26-28%, and increases SOx, PM, and Hg emissions due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 25 through Table 27.

Table 25: Annual Demand and Energy Values for a Small House New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	5	11,341	1,341	5	26,649	0	0	-15,308	1,341
St. Cloud	6	12,032	1,142	6	25,705	0	0	-13,673	1,142
Minneapolis	5	12,436	1,083	5	25,292	0	0	-12,856	1,083

Table 26: Economics of Conventional and GHP HVAC Systems for a Small House New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 9,900	$ 254	$ 2,441	$ 40,113	$ 22,500	$ 292	$ 1,874	$ 39,936	$ 529	26.5	$ 177	0.4%
St. Cloud	$ 9,900	$ 254	$ 2,251	$ 38,219	$ 22,500	$ 292	$ 1,810	$ 39,167	$ 403	36.2	$ (949)	-2.5%
Minneapolis	$ 9,900	$ 254	$ 2,274	$ 38,621	$ 22,500	$ 292	$ 1,780	$ 38,802	$ 456	32.5	$ (181)	-0.5%

Table 27: Annual Emissions Values for a Small House New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	34,628	51	54	10	0.0005	34,772
	GHP	44,298	119	98	21	0.0012	44,434
	Reduction	-9,670	-68	-44	-11	-0.0006	(9,662)
	% Change	27.9%	134.6%	81.2%	110.9%	119.9%	27.8%
St. Cloud	Conventional	33,436	54	55	10	0.0006	33,570
	GHP	42,729	114	94	20	0.0011	42,860
	Reduction	-9,293	-61	-40	-10	-0.0006	(9,290)
	% Change	27.8%	113.4%	72.5%	95.7%	102.5%	27.7%
Minneapolis	Conventional	33,413	55	56	10	0.0006	33,546
	GHP	42,042	112	93	20	0.0011	42,172
	Reduction	-8,629	-57	-37	-9	-0.0005	(8,626)
	% Change	25.8%	103.1%	66.9%	87.6%	93.6%	25.7%

Small House, Existing Building

The small house existing building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The small house existing building with the GHP HVAC system had higher electrical costs than the conventional HVAC system but no natural gas costs. The annual savings from the installation provided a net decrease in life cycle costs. The installation of a GHP system in a small house existing building increases CO2 equivalent GHG emissions approximately 22-24%, and increases SOx, PM and Hg emissions due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 28 through Table 30.

Table 28: Annual Demand and Energy Values for a Small House Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	6	11,802	1,711	6	29,360	0	0	-17,558	1,711
St. Cloud	6	12,713	1,397	6	28,091	0	0	-15,378	1,397
Minneapolis	6	13,223	1,367	6	27,911	0	0	-14,688	1,367

Table 29: Economics of Conventional and GHP HVAC Systems for a Small House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 10,440	$ 254	$ 2,918	$ 45,679	$ 23,040	$ 292	$ 2,057	$ 42,697	$ 823	16.2	$ 2,982	6.5%
St. Cloud	$ 10,440	$ 254	$ 2,605	$ 42,534	$ 23,040	$ 292	$ 1,973	$ 41,674	$ 595	23.0	$ 860	2.0%
Minneapolis	$ 10,440	$ 254	$ 2,676	$ 43,442	$ 23,040	$ 292	$ 1,948	$ 41,372	$ 690	19.9	$ 2,070	4.8%

Table 30: Annual Emissions Values for a Small House Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	39,748	53	59	10	0.0006	39,917
	GHP	48,805	131	108	23	0.0013	48,955
	Reduction	-9,057	-78	-49	-12	-0.0007	(9,038)
	% Change	22.8%	148.3%	82.4%	118.2%	129.5%	22.6%
St. Cloud	Conventional	37,568	57	60	11	0.0006	37,722
	GHP	46,695	125	103	22	0.0012	46,839
	Reduction	-9,127	-68	-44	-11	-0.0006	(9,117)
	% Change	24.3%	120.6%	73.2%	99.8%	107.7%	24.2%
Minneapolis	Conventional	38,063	59	61	11	0.0006	38,218
	GHP	46,396	124	102	22	0.0012	46,539
	Reduction	-8,333	-65	-41	-10	-0.0006	(8,321)
	% Change	21.9%	110.8%	67.6%	91.9%	99.2%	21.8%

Large House, New Construction

The large house new construction building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The large house new construction building with the GHP HVAC system had higher electrical costs than the conventional HVAC system but no natural gas costs. The annual savings from the installation provided a net increase in life cycle costs. The installation of a GHP system in a large house new construction building increases CO2 equivalent GHG emissions approximately 27-30%, and increases SOx, PM, and Hg emissions due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 31 through Table 33.

Table 31: Annual Demand and Energy Values for a Large House New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	8	18,745	1,695	8	39,656	0	0	-20,911	1,695
St. Cloud	9	19,802	1,404	9	38,498	0	0	-18,696	1,404
Minneapolis	9	20,424	1,344	9	38,041	0	0	-17,617	1,344

Table 32: Economics of Conventional and GHP HVAC Systems for a Large House New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 14,700	$ 254	$ 3,380	$ 55,346	$ 33,300	$ 292	$ 2,764	$ 57,455	$ 578	38.7	$ (2,108)	-3.8%
St. Cloud	$ 14,700	$ 254	$ 3,104	$ 52,606	$ 33,300	$ 292	$ 2,686	$ 56,512	$ 381	69.8	$ (3,906)	-7.4%
Minneapolis	$ 14,700	$ 254	$ 3,133	$ 53,070	$ 33,300	$ 292	$ 2,609	$ 55,585	$ 486	55.3	$ (2,515)	-4.7%

Table 33: Annual Emissions Values for a Large House New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	51,101	83	84	16	0.0009	51,305
	GHP	65,919	176	146	31	0.0017	66,122
	Reduction	-14,819	-93	-61	-15	-0.0009	(14,818)
	% Change	29.0%	111.3%	72.4%	94.6%	101.0%	28.9%
St. Cloud	Conventional	49,434	88	86	16	0.0009	49,625
	GHP	63,995	171	141	30	0.0017	64,191
	Reduction	-14,560	-83	-56	-13	-0.0008	(14,566)
	% Change	29.5%	94.2%	65.0%	82.0%	86.7%	29.4%
Minneapolis	Conventional	49,762	91	87	17	0.0009	49,952
	GHP	63,235	169	140	29	0.0017	63,429
	Reduction	-13,473	-78	-52	-13	-0.0007	(13,477)
	% Change	27.1%	86.1%	59.9%	75.1%	79.4%	27.0%

Large House, Existing Building

The large house existing building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher electrical energy consumption values than the conventional HVAC system. The large house existing building with the GHP HVAC system had higher electrical costs than the conventional HVAC system but no natural gas costs. The annual savings from the installation provided a net decrease in life cycle costs. The installation of a GHP system in a large house existing building increases CO2 equivalent GHG emissions approximately 24-26%, and increases SOx, PM and Hg emissions due to the increased electric consumption. Simulation values for the conventional and GHP systems are shown in Table 34 through Table 36.

Table 34: Annual Demand and Energy Values for a Large House Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	10	19,269	2,243	10	43,439	0	0	-24,170	2,243
St. Cloud	10	20,650	1,760	10	41,838	0	0	-21,188	1,760
Minneapolis	10	21,479	1,757	10	42,136	0	0	-20,657	1,757

Table 35: Economics of Conventional and GHP HVAC Systems for a Large House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 15,450	$ 254	$ 4,075	$ 63,399	$ 34,050	$ 292	$ 3,020	$ 61,308	$ 1,017	19.7	$ 2,092	3.3%
St. Cloud	$ 15,450	$ 254	$ 3,592	$ 58,534	$ 34,050	$ 292	$ 2,914	$ 60,022	$ 640	33.7	$ (1,488)	-2.5%
Minneapolis	$ 15,450	$ 254	$ 3,707	$ 59,935	$ 34,050	$ 292	$ 2,875	$ 59,545	$ 795	27.2	$ 389	0.6%

Table 36: Annual Emissions Values for a Large House Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	58,419	86	91	17	0.0009	58,661
	GHP	72,208	193	160	33	0.0019	72,430
	Reduction	-13,789	-107	-68	-17	-0.0010	(13,770)
	% Change	23.6%	125.1%	74.5%	102.6%	111.2%	23.5%
St. Cloud	Conventional	55,032	92	92	17	0.0010	55,250
	GHP	69,547	186	154	32	0.0018	69,761
	Reduction	-14,515	-94	-62	-15	-0.0009	(14,511)
	% Change	26.4%	102.4%	66.9%	87.2%	93.1%	26.3%
Minneapolis	Conventional	56,375	96	95	18	0.0010	56,597
	GHP	70,042	187	155	32	0.0019	70,257
	Reduction	-13,667	-92	-60	-15	-0.0009	(13,661)
	% Change	24.2%	96.0%	62.8%	81.8%	87.3%	24.1%

Comparative Analysis – Results Across All Building Types

From the results found in this study, installation of ground source heat pumps in the state of Minnesota provides both benefits and challenges from a mass implementation perspective. Based on current energy rates installation of GHP systems reduces total (natural gas and electricity) annual energy costs and maintenance costs required to operate HVAC systems. Installation of GHP systems reduces greenhouse gas emissions in commercial and institutional buildings, but increases greenhouse gas emissions in residential buildings. The installation of GHP systems in all building types and sizes increases other pollution, including sulfur dioxide, particulate matter, and mercury, when compared with conventional HVAC systems.

Current Status and Market Potential of GHPs

The second primary task of this study was to identify current installations of GHPs, available financial incentives, manufacturers and installers, economic development potential, and barriers to more widespread, cost effective use of the technology in Minnesota.

- Few GHP systems are currently installed in Minnesota. Current penetration rates are around one and one quarter percent per year, or 1,011 reported shipments of GHPs to Minnesota in 2005.
- No state or federal funds are currently designated specifically for the development of GHPs in Minnesota. The utilities in the state either include GHP systems in their custom programs or provide incentives for GHP systems ranging from $150 - $300 per ton as a part of their current prescriptive incentives.
- There are one manufacturer (Econar) and twenty-nine installation companies of GHP systems listed in Minnesota. A complete list of installers is included in Appendix A.
- A dramatic increase in Minnesota GHP installations to over 5,000 annually in selected residential, commercial, and institutional applications would likely see an economic benefit of $4.8 million annually in reduced energy costs and $86.6 million annually in increased installation business. These benefits would create a net growth of 1,600 jobs, taking into account some job losses in the LP and fuel oil industries. The increase would, however, increase electric consumption and summer peak electric demand and result in increased greenhouse gas and other emissions.
- Many barriers to entry still exist for GHP systems in Minnesota, including
    - high first costs,
    - cost uncertainty,
    - life cycle costs,
    - low incentives,
    - local utility rates,
    - low gas prices,
    - low education about the systems, and
    - no organized promotion of the technology.
- Other states have implemented programs to combat these types of barriers, including
    - attractive incentives,
    - trade ally training,
    - customer training,
    - promotion of success stories,

- advertising to target customers,
- public communications,
- organized instructional reference tools, and
- a professional organization

Recommendations for Future Work

The analysis presented in this study adequately and accurately represents the energy, economic, and environmental impacts for the specific buildings and system types presented, for the state of Minnesota. However, due to the constraints of the study, the scope had to be limited in several aspects. Because the study did not evaluate performance of individual systems, further study of actual system performance in Minnesota would provide a better basis to further evaluate the potential benefits of GHP systems within Minnesota.

The thermal performance of GHP systems for this study was based on a single assumed pair of values for all building types: 14.1 EER cooling and 3.3 COP heating. In reality, the performance of different systems are likely to be better or not as good as assumed, due to variables in installation, site conditions, operating practices, and many others. No detailed investigation has been done regarding GHP performance for Minnesota installations. Thus, research on the actual field performance of GHP systems in Minnesota is needed to bridge this information gap.

It was necessary to limit the scope of the study to include only one large and one small representative building for each of the three climate zones within the state of Minnesota for each of the three building types. While this can provide an overview of the general behaviors of GHP characteristics within the state, it does not adequately assess the potential benefits and limitations for the implementation of this technology in the state. Further analysis, including in-depth studies of additional building types would allow further insight into potential economic and environmental effects.

The installed cost for GHP systems is highly variable. Individual building specifics such as local geology, cost of loop piping, costs of antifreeze, etc., can substantially affect the total installed cost of the system. In addition, determining a reasonable total installed cost for these systems is made more difficult by the large range of values presented in previous studies. The difficulty in comparing construction costs between studies is augmented due to the differences in system boundaries utilized in each study. In many studies, it is unclear if equipment such as ductwork, chilled and hot water loop piping, pumps, etc. is included in the installed costs. A further investigation into total installed costs for a variety of HVAC systems would be beneficial.

The scope of this study examined only a typical large and small building for each category, which therefore included a comparison using only one typical efficiency value for each of the conventional and GHP systems. Further analysis using the costs and efficiencies of a variety of both conventional and GHP systems would allow a more precise comparison on savings, which could be utilized to determine the most cost effective conditioning systems for more specific applications.

The scope of this study included the comparison of emissions and economics to the most typical fuel source for service water and space heating needs. Within the state of Minnesota, these needs are met by a combination of natural gas, electricity, LP, distillate oil, residual oils, and other sources. Further analysis, including both the economic and emissions comparison for a variety of fuel sources is recommended. In addition, the application of these emissions and economic comparisons would be recommended for the entire state of Minnesota based on percentages of facilities utilizing each fuel source.

In some cases, the implementation of GHP systems resulted in a net increase in both greenhouse gas emissions as well as other emissions. In other cases, GHP systems resulted in a net decrease in greenhouse gas emissions but increased other emissions. Changes in the electrical generation capability and source fuels will greatly affect the emissions for the GHP systems. Minnesota is strategically poised to be able to utilize wind, biomass, and other alternative fuels sources to decrease these specific emissions values. Specific emissions values were considered to be static in this study. Further analysis that included specific emissions values based on changes in the electrical generation mix over the course of the service life would provide additional insight into potential future emissions reductions.

1 Literature Review and Technical Assumptions

1.1 Introduction

Rising energy costs and concern over evidence of climate effects from greenhouse gas emissions are driving rapid development of renewable and efficient energy technologies. One area of technology development is in improving the efficiency of heating, ventilation and air conditioning (HVAC) equipment and systems in buildings. HVAC systems account for over 40% of electric energy consumption and over 90% of gas consumption in residential and commercial buildings (1). In schools, HVAC systems account for over 25% of electric energy consumption and over 90% of gas consumption (1). Using the most efficient HVAC system in these buildings has potential to contribute to energy reductions, economic savings, and emissions cutbacks.

No savings estimate or study has been completed to address the behaviors, annual energy use, and economics of GHP systems specifically in the state of Minnesota. In this study, GHP HVAC systems are compared with conventional HVAC systems. Primary system differences include heating and cooling efficiencies, energy source, and system performance characteristics. Heating and cooling efficiencies of HVAC and GHP equipment are all assumed values. The study assumes ENERGY STAR® labeled efficiency values, Federal Energy Management Program recommended efficiencies, or typical system efficiencies seen in operation (2, 3). All conventional systems are analyzed with natural gas heat and electric cooling systems. Heat pump systems use electricity to drive both the heating and cooling conditioning. System performance characteristics are determined in the modeling software. Detailed discussions of assumptions used in this study are included in Section 1.3.

The primary purpose of this project was to

- Determine the difference in energy consumption, user costs, and amounts of pollutants and carbon dioxide emissions for Ground Source Heat Pumps (GHPs) as compared to conventional Heating, Ventilation and Air Conditioning (HVAC) systems in Minnesota residential, commercial and institutional buildings used for heating and cooling air and water heating, and;
- Identify current installations of GHPs, available financial incentives, manufacturers and installers, economic development potential, and barriers to more widespread, cost effective use of the technology in Minnesota.

This chapter details some background reviews that were conducted to determine reasonable operating parameters as well as reasonable technical assumptions for creating the building models.

1.1.1 Definition of Terms

This report uses some technical terms that may not be familiar to all readers, or may be used in a context more specific than what is used in general dialogue. For purposes of clarity, some terms and units are defined here.

BTU	British Thermal Unit, a standard English-system unit of energy.
BTUH	BTU per hour, a rate of energy use.

COP	Coefficient of Performance, the amount of energy supplied by a device per unit of energy supplied to the device (no units).
Demand	Rate at which energy is used. Measured in kW, BTUH.
EER	Energy Efficiency Ratio, an efficiency measure for commercial air conditioning systems (BTU Output / Watt-hr Input).
SEER	Seasonal Energy Efficiency Ratio, ratio of BTU of cooling output during its normal annual usage divided by the total electric energy input in Watt-hr during the same period (BTU $Output_{season}$ / Watt-hr $Input_{season}$).
Energy consumption	Quantity of energy used for a given application. Measured in kWh, MWh, Therms.
kW	kilowatt, a rate of electric energy use.
kWh	kilowatt-hour, an amount of electric energy equivalent to 1 kW supplied for 1 hour. When discussing the same type of energy, 1 kWh = 3,413 BTUH
MWh	megawatt-hour, an amount of electric energy equal to 1,000 kWh.
Therm	an amount of energy, equal to 100,000 BTU, or 0.1 mcf of natural gas.
Ton	Unit of cooling demand, equal to 12,000 BTUH of heat removed from a space

1.2 Literature Review

Many studies have shown that geothermal[1] heat pumps (GHPs) show significant efficiency and economic improvements over traditional HVAC systems (4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19). Many of these studies show benefits in climates warmer than that of Minnesota (14, 15, 17, 18, 19), but some studies show specific benefits of installing GHP systems in northern climates (5, 6, 9, 10, 13). One of these studies showed 29% and 36% annual energy cost savings in commercial and institutional buildings, respectively, from surveys conducted comparing GHP systems to conventional systems (4). This study also detailed savings compared to conventional system types. GHP systems were shown to provide more energy cost savings than a gas-heat building when compared to an all-electric building conventional system.

One study in particular detailed the energy, economic, and emissions effects of installing GHP systems in Wisconsin, a neighboring state to Minnesota, with a similar climate (9). This study shows annual energy cost savings for all buildings examined; however, payback periods ranged from 10 to 24 years. CO2 emissions were reduced in commercial and institutional buildings, but were increased in all residential buildings. Results in Minnesota are expected to be similar in nature to these results in Wisconsin.

[1] Sometimes called ground source. Heat pumps use the relatively steady temperature of the ground as a heat source or sink, usually for space conditioning. Geothermal heat pumps should not be confused with use of such as volcanic geothermal steam that may be used to generate electricity.

Despite the lack of a formal study, GHP systems are developing a small market in Minnesota already. In 2005, there were 1,011 reported GHP shipments to Minnesota (20). These installations represent a current annual penetration rate for GHP systems of about one and one quarter percent (1.27%).

The economics of installing GHP systems extend beyond annual energy costs. Many studies have shown a decrease in maintenance costs for GHP systems as compared with conventional HVAC systems (4, 21, 22, 23, 24). This effect generally has a smaller financial impact than energy cost savings.

Some barriers to entry still exist in Minnesota, keeping the installation market relatively small. These barriers are detailed later in this report, but they include added installation costs and the uncertainty about these costs. The upfront costs of a GHP system and the resulting lifetime cost-effectiveness can vary significantly and is dependant on factors such as proper sizing of installation, local weather conditions and geology (25, 26, 27, 28).

1.3 Technical Assumptions

To achieve the technical goals of this study, three main tasks were required to be completed. First was an energy analysis for each type of building. The energy analysis required assumptions about climate zones in which buildings are located and characteristic of the building types being analyzed, including characteristics of the HVAC systems and water heating systems expected to operate in each type of building. Second, economics for each building were compared. This economic comparison required up front installation costs for each type of system, O&M costs including energy and other maintenance costs for each system. Finally, emissions resulting from the energy consumption in each building were compared. This comparison required specific emissions rates for each type of energy use: electricity and heating fuels. The assumptions used to conduct the analysis within each of these three tasks are detailed in this chapter.

1.3.1 Assumptions Required for Energy Analysis

To determine the energy use, a consistent building modeling method was required. From its widespread use in the field, the DOE 2.1e (DOE2) building simulation program was selected to model each building. The primary assumption of this study is that this simulator can provide accurate representations of building energy consumption and system performance. Using climate zones described below, Visual DOE was used to simulate heating and cooling loads for each building.

As with any simulation, the results can only be expected to be as accurate as the model setup used for the buildings and systems. The assumed values regarding climate zones and building characteristics used as inputs used are presented in the following sections.

1.3.1.1 Assumptions Regarding Climate Zones

Three climate zones were selected in conjunction with the suggested climate zone data supplied by the Minnesota DOC. The Minnesota DOC climate zones were defined using heating degree-days (HDD) and cooling degree-days (CDD), based on population-weighted average values in each zone.

Representative locations were selected for each of three climate zones considered in this study. The building locations were selected based on predefined locations available in the DOE2.1e TMY2 (Typical Meteorological Year) weather data library to facilitate ease of analysis.

The locations selected were:

- Zone 1-Duluth (North)
- Zone 2-St. Cloud (Mid)
- Zone 3-Minneapolis (South)

The average HDD and CDD values for each climate zone are shown in the left side of Figure 1. The TMY2 data for the three selected locations above have HDD and CDD values shown in the right side of Figure 1. These cities were chosen because they most closely represent the areas selected in each zone, particularly with respect to HDD, which dominates HVAC energy consumption in Minnesota.[2]

Figure 1: HDD and CDD Values in Zones Used in This Study

Population Weighted Average			Utilized TMY2 Values		
Zone	**HDD**	**CDD**	**City**	**HDD**	**CDD**
North	9,921	99	Duluth	10,213	39
Mid	8,956	193	St. Cloud	8,995	159
South	8,029	280	Minneapolis	8,002	268

For the purposes of this study, the climate of each listed city is sufficiently representative of the corresponding zone of the state. Duluth is representative of the climate in the Northern counties of the state; St. Cloud is representative the climate in counties through the middle of the state; and Minneapolis is representative of the climate in the Southern counties of the state. An error analysis was conducted, comparing the population-weighted average HDD in each county in each part of the state to the HDD of the selected city. The average difference in values for each region is shown in Figure 2. For purposes of brevity, the city used for the climate in each region is listed in results tables, but these values are representative of each region in its entirety.

Figure 2: Average Population Weighted Difference in HDD between the Selected Zone / City and the Rest of the Region

Zone HDD Valules		Utilized TMY2 Values	
North	2.79%	Duluth	3.58%
Mid	3.40%	St. Cloud	3.29%
South	2.85%	Minneapolis	3.05%

[2] The TMY2 data input into DOE2.1e simulation provides more accurate results than a bulk HDD / CDD annual average energy consumption, especially when comparing interactive building models. Studies have shown a very high dependence on balance point of a building for determining HVAC energy consumption when using an HDD/CDD method. Using the DOE2.1e simulation method eliminates the error associated with guessing a balance point temperature.

1.3.1.2 Heating and Cooling Loads

The TMY2 data were used in place of HDD/CDD or daytype/seasonal analysis. The DOE2 simulation of heating and cooling loads and hours of operation for each building type is assumed to be accurate for the three climate zones listed here.

1.3.1.3 Utility Hourly Loads

Hourly loads provided by utilities in Minnesota were requested but were not made available for this report. In place of this 8,760 (year-long) hour-by-hour comparison of demand, a summer and winter building peak were calculated for each building simulation. These building peaks are assumed to be representative of times when the utility load is at or near its peak.

1.3.1.4 Assumptions Regarding Building Characteristics

Three building types were selected for analysis and inclusion in this study: commercial, institutional, and residential. Large and small buildings were required for each type, for a total of six buildings in each climate zone. Each building type may be represented by several specific building classes (commercial buildings include retail stores, offices, etc). For the purposes of this study, one specific building class was assumed to be representative of the building type. Modeling a specific class of buildings is more accurate than attempting to combine characteristics of multiple classes into one model. For example, modeling an office building or retail store on its own is more accurate than attempting to incorporate characteristics of both buildings in an attempt to obtain data representative of both buildings at once. Based on the literature reviewed (29, 30) as well as Michaels Engineering's experience in the industry, the building classes selected are consistent with the buildings that have shown both significant implementation of GHP systems and significant potential for energy savings and emissions reductions within each building type.

The building classes and associated characteristics for new construction and existing buildings are presented in Figure 3 and Figure 4. These characteristics include building size (square feet), number of floors, aspect ratio, energy-related parameters (such as occupancy, lighting levels, and ventilation levels), and insulation levels. Sizes were assumed based on similar studies and available data (9, 29, 30, 31, 32). Number of floors and aspect ratios were assumed based on typical building data (29, 30, 31, 32). Energy-related parameters including lighting power density, equipment power density, and insulation levels were assumed based on current building codes for new construction and based on typical building practice from ~20 years prior to this report for existing buildings (2, 3).

Building parameters were collected from a variety of sources. Residential sizes were taken from census data. School sizes were taken from compiled Minnesota Department of Education data. Commercial building sizes were taken from federally commissioned studies (29, 30). These studies included values for aspect ratios, heating and cooling typical systems, etc. ASHRAE 90.1-2004 was referenced for building shell properties such as R-Values and window glazing coefficients and U-values (2, 3).

Office buildings were selected as representative of commercial buildings, schools as representative of institutional buildings, and single-family homes as representative of residential buildings.

Figure 3: Assumed Building Characteristics-New Construction

	Small Office	Large Office	Small School	Large School	Small Residential	Large Residential
Building Size (sq. ft.)	13,006	75,060	69,114	386,328	1,800	3,000
Number of floors	1	3	1	2	1	2
Aspect Ratio	1.2	2.2	IRR	IRR	1.2	1.6
Floor to Floor Height (ft)	13	13	13	13	9	9
Plenum Height (ft)	4	4	4	4	N/A	N/A
Zones per Floor	5	5	5	5	1	1
Perimeter Zone Depth (ft)	15	15	20	20	N/A	N/A
Glazing Fraction	0.40	0.40	0.18	0.18	0.12	0.12
Occupancy (ft^2/person)	275	275	75	75	600	600
Ventilation (cfm/person)	17	17	15	15	15	15
Lighting (W/ft^2)	1.0	1.0	1.2	1.2	0.7	0.7
Plug Loads (W/ft^2)	1.3	1.3	0.8	0.8	1.1	1.1
Construction Type	Steel Frame	Steel Frame	Mass	Mass	Wood Frame	Wood Frame
Roof Insulation R-Value	22	22	22	22	38	38
Wall Insulation R-Value (ASHRAE Zone 6)	13+3.8 ci	13+3.8 ci	9.5 ci	9.5 ci	19 or 13+5 ci	19 or 13+5 ci
Wall Insulation R-Value (ASHRAE Zone 7)	13+7.5 ci	13+7.5 ci	11.4 ci	11.4 ci	19	19
Glazing SHGC (ASHRAE Zone 6)	0.39	0.39	0.39	0.39	N/A	N/A
Glazing SHGC (ASHRAE Zone 7)	0.39	0.39	0.49	0.49	N/A	N/A
Glazing U-Value	0.57	0.57	0.57	0.57	0.35	0.35
Infiltration (ACH)	0.2	0.2	0.2	0.2	0.2	0.2

IRR = Irregular Shape
ci = Continuous Insulation

Figure 4: Assumed Building Characteristics-Existing Building

	Small Office	Large Office	Small School	Large School	Small Residential	Large Residential
Building Size (sq. ft.)	13,006	75,060	69,114	386,328	1,800	3,000
Number of floors	1	3	1	2	1	2
Aspect Ratio	1.2	2.2	IRR	IRR	1.2	1.6
Floor to Floor Height (ft)	13	13	13	13	9	9
Plenum Height (ft)	4	4	4	4	N/A	N/A
Zones per Floor	5	5	5	5	1	1
Perimeter Zone Depth (ft)	15	15	20	20	N/A	N/A
Glazing Fraction	0.40	0.40	0.18	0.18	0.12	0.12
Occupancy (ft^2/person)	275	275	75	75	600	600
Ventilation (cfm/person)	17	17	15	15	15	15
Lighting (W/ft^2)	1.6	1.6	1.7	1.7	0.7	0.7
Plug Loads (W/ft^2)	1.3	1.3	0.8	0.8	1.1	1.1
Construction Type	Steel Frame	Steel Frame	Mass	Mass	Wood Frame	Wood Frame
Roof Insulation R-Value	9.1	9.1	10	10	25	25
Wall Insulation R-Value (ASHRAE Zone 6)	4.0	4.0	4.0	4.0	11	11
Wall Insulation R-Value (ASHRAE Zone 7)	4.0	4.0	4.0	4.0	11	11
Glazing SHGC (ASHRAE Zone 6)	0.52	0.52	0.73	0.73	0.73	0.73
Glazing SHGC (ASHRAE Zone 7)	0.52	0.52	0.73	0.73	0.73	0.73
Glazing U-Value	0.7	0.7	0.7	0.7	0.55	0.55
Infiltration	0.5	0.5	0.5	0.5	0.6	0.6

IRR = Irregular Shape
ci = Continuous Insulation

1.3.1.5 Assumptions Regarding HVAC System Characteristics

Within each building type, a variety of HVAC systems may be common and can depend on building characteristics, building function, and HVAC designer preferences. For each of the building sizes and types in Figure 3 and Figure 4, one representative conventional HVAC system was assumed. The conventional systems assumed for each building type are listed in Figure 5. Efficiencies of commercial, institutional, and residential cooling systems are assumed based on current code values (2, 3). Efficiencies of large commercial, large and small institutional, and large and small residential heating systems are assumed based on Energy Star levels. The efficiency of the small commercial heating system (rooftop units) is assumed based on Michaels Engineering's experience in the industry. The assumptions regarding the systems also include expected equipment useful life. All conventional systems use natural gas for space heating and water heating, and electricity from a utility to run the cooling system.

All efficiencies listed in Figure 5 are the nominal efficiencies at standard rating conditions. Determining the actual operating efficiency of each piece of equipment is dependant on factors such as loading conditions, outdoor conditions, and specific performance characteristics. Average operating efficiencies achieved as a result of operating in each specified climate are listed in the results section. Due to the nature of this study, the typical efficiency adjustments internal to the DOE 2.1e engine were assumed to be adequate to represent the operations of the systems over the year. These adjustments are assumed to sufficiently define and account for annual operating efficiency characteristics. However, significant uncertainties can be expected in the results of this study as a result of uncertainties present in the assumptions. Also outside the scope of this study was a sensitivity analysis to show how the uncertainty in efficiencies would affect the energy and pollutant results. This important factor remains for future work.

Ground source heat pump systems assumed for each building type are listed in Figure 6. Efficiencies of commercial, institutional, and residential heating and cooling systems are assumed based on minimum levels required to achieve current incentives in the state, identical to the current values for ENERGY STAR® labeled equipment. The assumptions regarding the systems also include expected equipment useful life.

The same conventional and GHP systems were considered for both new construction and existing building retrofit analysis for each building type and size. The installation of a GHP system is a significant project with substantial incremental costs associated with it. Therefore, the vast majority of GHP systems installed are either installed at the new construction stage, during the course of a major building renovation, or at the end of life of the existing HVAC system. In all three of these options, the conventional HVAC system would be subject to current building codes. Because of this situation for both the new construction and existing building retrofit conditions, incremental costs are considered rather than full costs. While many schools currently do not have air conditioning (33), due to the assumption that the buildings are compared against retrofits with both heating and cooling installed so the same conditioning is achievable, the energy comparisons for retrofit schools are still considered valid.

Figure 5: Assumed System Characteristics – Conventional HVAC Systems

	Small Office	Large Office	Small School	Large School	Small Residential	Large Residential
Conventional System Type	PVAV	VAV	VAV	VAV	Split	Split
Fan Control	Variable	Variable	Variable	Variable	Constant	Constant
Conventional Cooling Type	DX	WCC	ACC	WCC	DX	DX
Conventional Heating Type	F	GB	GB	GB	F	F
Conventional Cooling EER	12.0	16.7	12.0	20.8	14 SEER	14 SEER
Conventional Heating Eff	80%	85%	85%	85%	92%	92%
Heating System Useful Life (Years)	15	25	25	25	18	18
Cooling System Useful Life (Years)	20	23	23	23	15	15
Ductwork Useful Life (Years)	30	30	30	30	30	30
VAV Box Useful Life (Years)	20	20	20	20	N/A	N/A
Cooling Tower Uesful Life (Years)	N/A	20	N/A	20	N/A	N/A
Pump Useful Life (Years)	N/A	20	N/A	20	N/A	N/A
Fan Useful Life (Years)	25	25	25	25	25	25

PVAV = Packaged Variable Air Volume
VAV = Variable Air Volume
Split = Split Air Conditioning System with Outdoor Condenser
DX = Direct Expansion
WCC = Water Cooled Chiller
F = Furnace (includes Gas-Fired Heat for the Packaged Rooftop Unit in the Case of the Small Office)
GB = Gas Boiler

Figure 6: Assumed System Characteristics – GHP HVAC Systems

	Small Office	Large Office	Small School	Large School	Small Residential	Large Residential
GHP Cooling EER	14.1	14.1	14.1	14.1	14.1	14.1
GHP COP	3.3	3.3	3.3	3.3	3.3	3.3
System Useful Life (Years)	19	19	19	19	19	19
Loop Useful Life (Years)	100	100	100	100	100	100
Ductwork Useful Life (Years)	30	30	30	30	30	30
Pump Useful Life (Years)	N/A	20	N/A	20	N/A	N/A
Fan Useful Life (Years)	25	25	25	25	25	25
ERV Effectiveness	60%	60%	60%	60%	N/A	N/A
Orientation	Vertical	Vertical	Vertical	Vertical	Horizontal	Horizontal

Efficiencies of HVAC systems are consistent with Federal Energy Management Program (FEMP) recommended efficiencies, typical installed values for the building population in Minnesota, state and local building codes, utility GHP system program assumptions, information presented by technical engineering societies, and Michaels Engineering's experience in the industry, as applicable (2, 3).

1.3.1.6 Assumptions Regarding Water Heating System Characteristics

Based on 2003 Commercial Building Energy Consumption Survey (CBECS) and 2001 Residential Energy Consumption Survey (RECS) data, 99% of commercial water heating systems and 85% of residential water heating systems are either natural gas or electric; therefore, these are the only two fuel sources considered in this study (32).

For each building type and size, a cursory review of the water heating needs was completed to determine if gas or electric heating provided an economic advantage. Based on this cursory review, gas water heating was assumed to be installed for all buildings with conventional HVAC systems. For buildings with GHP systems implemented, gas systems remained in use for the large office, small school, and large school. However, in the small office, small residential, and large residential, the ability to eliminate the natural gas consumption entirely resulted in an assumption that electrical water heating would be the more economical option in these building cases.

For buildings where electric water heating was chosen, a desuperheater option was considered for the GHP systems. These buildings were modeled with and without the desuperheater option to show effects of incorporation of this feature. A desuperheater uses energy from the GHP refrigeration loop to provide a portion of the facilities' hot water needs. The remaining hot water must be produced using a secondary electric heating element.

A desuperheater heat pump option is not expected to have a significant impact on the operating efficiency of the GHP system during the heating season, but the heat available to the space will decrease slightly. This results in either specifying a larger GHP system size or requiring that the GHP operate for a greater number of hours. At peak load conditions, the entire water heating load will be served by the supplemental electric resistance heaters. During the cooling season, the efficiency of the heat pump is expected to increase with the desuperheater option. This also results in less heat being sent to the well field and can result in additional pumping energy savings.

1.3.2 Annual Hours of Operation

The DOE2 simulation of heating and cooling loads and hours of operation for each building type and size is assumed to be accurate for the three climate zones listed in Section 1.3.1.1.

1.3.3 Assumptions Required for Economic Analysis

Economic analysis required assumptions regarding conventional and GHP system costs. These costs include total installed costs, annual maintenance and other O&M costs (other than energy), and annual energy costs, based on current utility rates. A simple payback analysis and a life cycle cost analysis were assumed to be the best methods to compare the conventional and GHP systems' economics.

1.3.3.1 Assumptions Regarding System Installed Costs and O&M Costs

From previous studies (4, 9, 13, 18, 26, 27), an industry survey in Minnesota, and interviews with designers (34), cost estimates were determined for conventional systems and GHP systems, shown in Figure 7 and Figure 8. Because there are an infinite number of possible installation options, a survey was sent out to Minnesota contractors, and some Minnesota and Wisconsin HVAC system designers were interviewed to estimate system costs. Installed costs include all equipment and installation labor for the system, air handling system, related piping and ductwork, and, in the case of the GHP system, drilling and installing the well field. In the commercial and institutional GHP systems, costs also include energy recovery ventilators (ERVs), which are typically installed to maintain smaller well field sizes and to reduce the ventilation temperature differential to ensure that the heat pump can provide sufficient temperature gain to the mixed air. The costs do not assume any distinction between the number of wells or well depth or orientation, as each of these parameters is site-specific. The figures also include estimates of maintenance costs for each system, normalized per square foot.

Operations and maintenance costs are significantly lower than energy costs for the buildings analyzed. As with total installed costs, maintenance costs will be building specific and were estimated from average values found in practice by RS Means and ASHRAE Handbooks. Heat pump maintenance is usually expected to be slightly less expensive than conventional system maintenance (21, 22, 23, 24), although this cost difference has significantly less impact on life cycle costs than the difference in energy costs. Estimated annual maintenance costs per square foot are listed in Figure 7 and Figure 8.

Figure 7: Conventional System Costs per Square Foot

Costs per Square Foot	Annual Maintenance	Total Installed Costs - New Construction	Total Installed Costs - Existing Building
Small Office	$ 0.27	$ 16.00	$ 17.00
Large Office	$ 0.15	$ 24.00	$ 25.00
Small School	$ 0.29	$ 24.00	$ 29.00
Large School	$ 0.10	$ 24.00	$ 29.00
Small Residential	$ 0.14	$ 5.50	$ 5.80
Large Residential	$ 0.08	$ 4.90	$ 5.15

Figure 8: GHP System Costs per Square Foot

Costs per Square Foot	Annual Maintenance	Total Installed Costs - New Construction	Total Installed Costs - Existing Building
Small Office	$ 0.26	$ 28.50	$ 31.50
Large Office	$ 0.12	$ 28.50	$ 31.50
Small School	$ 0.23	$ 28.50	$ 33.50
Large School	$ 0.08	$ 28.50	$ 33.50
Small Residential	$ 0.16	$ 12.50	$ 12.80
Large Residential	$ 0.10	$ 11.10	$ 11.35

Installation costs were not assumed to differ significantly for the locations considered. Per RS Means, the historical installation cost indices for the locations under considerations vary from the average cost index by less than 3%.

Due to the limitations of this study, costs are estimated as best as could be reasonably determined, but all costs for individual projects should still be considered on a site-specific basis. For example, heat pump well field costs may vary by over 100% relative to the average cost used here, due to local geological conditions (28), labor rates, etc. This study is not meant for any specific site building decision, but for assessing the general potential of heat pump systems in Minnesota. Some sites may be well suited for these systems, while others are not.

1.3.3.2 Assumptions Regarding Energy Costs

Four large utilities provide electric service to the vast majority of customers in the state. These companies serve different territories in the state and have a range of rates, depending on customer electricity consumption and demand. Xcel Energy serves throughout all three climate zones in this study; Alliant Energy serves the Southern part of the state; Minnesota Power serves the Northeast region; and Otter Tail Power serves the Western part of the state. Electric rates are shown in Appendix B. Although this does not include the entire rate structure for the utilities, these rates are typical for the facilities covered in this study.

These charges include demand and energy charges. The charges do not include taxes, fees, or fuel cost adjustments. Taxes and fees are expected to be proportional to energy consumption and should not significantly affect the results, compared to other uncertainties that cannot be improved for this study. Energy costs for the year are not expected to vary significantly based on variations in monthly fuel cost adjustments. Fuel cost adjustments represent the current prices for fuel in electricity generation. These charges are volatile and not well reported. From the information that is available, these adjustments may vary electric or natural gas costs by 5-10%. Gas charges are also subject to fuel cost adjustments. Due to the volatility of this factor, no fuel cost adjustments are used in this study.

In order to accurately reflect the economics for each area, the energy costs for the buildings considered were determined for each utility that serves customers in the three climate zones. Alliant Energy serves only the southern climate zone and Minnesota Power serves territory only in the northern and middle climate zones of the state. Both Xcel Energy and Otter Tail Power serve customers in all three climate zones of the state. The utilities considered for each climate zone are presented in Figure 9. Only the rate structures that would be applied to each building type are considered. The rates that apply to each building type are listed in Figure 10. Where two rates from the same utility may apply to a building, the rate that provides lower annual costs was assumed to be selected. Only one rate from each utility serving customers in each region was included in cost analyses.

Natural gas prices were supplied from an Energy Information Administration (EIA) study (35). The average 2007 retail natural gas price in Minnesota was $12.018 / MCF in the residential market and $9.866 / MCF in the commercial market. These fuel costs include both the fuel costs as well as distribution charges.

Figure 9: Utility Territories

Utility	Duluth (North)	St. Cloud (Mid)	Minneapolis (South)
Alliant Energy			X
Minnesota Power	X	X	
Otter Tail Power	X	X	X
Xcel Energy	X	X	X

Figure 10: Utility Rates Applying to Each Building Type

Utility	Rate	Small Office	Large Office	Small School	Large School	Small Residential	Large Residential
Alliant Energy	Residential					X	X
	General Service-Energy Only	X					
	General Service-Demand Metered		X	X	X		
Minnesota Power	Residential					X	X
	General Service-Energy Only	X	X	X	X		
	General Service-Demand Metered	X	X	X	X		
Otter Tail Power	Residential					X	X
	General Service-Energy Only	X		X	X		
	General Service-Demand Metered		X		X		
Xcel Energy	Residential					X	X
	General Service-Energy Only						
	General Service-Demand Metered	X	X	X	X		

1.3.3.3 Utility Incentives

There are currently no federal or state incentives specifically for GHP system installations. Many of the public utilities in Minnesota, however, do have incentive programs. A summary of utility incentive programs is shown in Figure 11. Smaller local utility providers may have incentives as well, but information regarding these programs is available only to the customers of these providers.

Figure 11: Utility Incentives for GHP Installation in Minnesota

	Base Cooling Incentive	Cooling Efficiency Incentive	Base Heating Incentive	Heating Efficiency Incentive	Desuperheater Incentive
	($/ton)	$/(EER-EER$_{min}$)	($/1000 BTU)	($)	($)
Alliant Energy					
Open Loop	$300	$150		$150	$200
Closed Loop	$300	$150		$150	$200
Minnesota Power					
Open Loop	$200				
Closed Loop	$150				
Ottertail Power					
Open Loop			$18		
Closed Loop			$18		
Xcel Energy-Residential					
Open Loop					
Closed Loop	$150				
Xcel Energy-Commercial					
Open Loop	Custom - $200/kW				
Closed Loop	Custom - $200/kW				

1.3.4 Assumptions Required for Emissions Analysis

The values in Figure 12 were determined from the 2005 Minnesota Public Utilities Commission (PUC) environmental disclosure reports for the major investor owned utilities, including Xcel Energy, Allete (Minnesota Power), Alliant Energy, Ottertail Power, and Dakota Electric. The specific emissions factors shown in Figure 12 were assumed to be representative of emissions associated with any electric consumption in this study. These values include both greenhouse gases and other emissions. Carbon dioxide (CO2) and nitrogen oxides[3] (NOx) are typically considered greenhouse gases. Sulfur dioxide (SO2), particulate matter (PM), and mercury (Hg) are also tracked here as other emissions.

In the results shown for the greenhouse gas emissions, global warming potential values were determined for each scenario. Global warming potential is a scale that uses CO2 as a reference and compares the global warming potential of a substance to the same mass of CO2 within a given timescale. The magnitude of the effect that each substance is attributed is a function of both the efficiency of the molecule as a greenhouse gas and the expected atmospheric lifetime. For the purposes of this study, only the effects of CO2 and N2O emissions were considered. In the Annual Emissions Values tables, “CO2 Eq.” expresses the equivalent CO2 greenhouse effect by combining the affects of CO2 and N2O emissions. N2O emissions were estimated based on EPA AP-42 Chapter 1 emissions factors (36).

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[3] N2O is documented to have the equivalent global warming potential of 296 times that of CO2, but is a very small portion of the nitrogen oxides emissions. Other nitrogen oxides can have an indirect greenhouse effect, but no widely accepted values for this effect have been published. Therefore, the effects of the other nitrogen oxides are not considered in this study.

Figure 12: Electric Utility Specific Emissions Factors

	CO2	SO2	NOx	N2O	PM	Hg
Units	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh	lbs/MWh
Electric Utilities	1,662	4.447	3.672	0.017	0.771	0.000044

The specific emissions factors shown in Figure 13 were assumed to be representative of emissions associated with non-electric space and water heating fuel use. The values in Figure 13 were derived from EPA AP-42 Chapter 1 emissions factors (36).

Figure 13: Natural Gas Specific Emissions Factors

	CO2	SO2	NOx	N2O	PM	Hg
Units	lbs/MMBTU	lbs/MMBTU	lbs/MMBTU	lbs/MMBTU	lbs/MMBTU	lbs/MMBTU
Residential Natural Gas Furnace	117.6	5.882E-04	9.216E-02	2.157E-03	7.451E-03	2.549E-07
Commercial Small Natural Gas Boiler	117.6	5.882E-04	9.804E-02	2.157E-03	7.451E-03	2.549E-07

2 Results and Comparative Analysis

Building models were constructed in DOE2 for three Minnesota climate zones for the categories of commercial, institutional, and residential buildings using the assumptions detailed in Section 1.3.1. In each scenario, the monthly and annual electric energy use, electric demand, and natural gas consumption values were determined for both the conventional HVAC system and a GHP HVAC system. Energy results were used with assumptions for economic factors and emissions factors from Sections 1.3.3 and 1.3.4, respectively, to determine the economic and emissions results for each case. All results for each building type are detailed in Section 2.1. Summarized results across building types are listed in Section 2.2.

Some analyses compare buildings based on daytypes, seasons, and annual hours of operation. This analysis, using DOE2 and TMY2 annual weather data, simulated building performance on an hourly basis for an entire typical year rather than for specific instances. The energy and demand figures presented in this chapter include all building energy and demand, including lighting, plug loads, HVAC, water heating, etc.

2.1 Model Results

2.1.1 Commercial Results

Commercial buildings were analyzed using building models for small and large office buildings. The small office conventional system is a relatively inexpensive packaged VAV system with cooling and heating efficiencies of 12.0 EER and 80%, respectively provided from the packaged rooftop unit and zone heating provided by an 80% efficient gas heater in each space. The large office conventional system is a VAV system with a water-cooled chiller with a 16.7 EER and a boiler with 85% rated efficiency for the cooling and heating, respectively. The comparisons between these systems and the GHP systems are detailed below.

2.1.1.1 Small Office, New Construction

The small office new construction building with the conventional HVAC system had electrical demand and energy consumption values ranging from 54 to 55 kW and 138 to 145 MWh, depending on location. The small office new construction building with the conventional HVAC system had natural gas consumption of 6,260 to 7,413 therms, depending on location.

The small office new construction building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, a decrease of 3 to 4 kW summer peak demand, an increase of 29 to 36 kW winter peak demand, and an increase of 24 to 29 MWh energy consumption, depending on location. Based on a cursory economic analysis, electric water heating was utilized in the GHP system. This allowed the gas consumption in the GHP case to be reduced to zero for all locations.

The demand and energy consumption values are presented in Figure 14 for the small office new construction GHP retrofit without the desuperheater water heating option. The demand and energy consumption values are presented in Figure 15 for the small office new construction GHP system with the desuperheater water heating option added.

The small office new construction building with the conventional HVAC system had total annual energy costs from $14,849 to $17,578, depending on location and utility. The small office new construction building with the GHP HVAC system had higher electrical costs but no natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $4,275 to $5,380, or 26% to 34% of the conventional HVAC system energy costs, depending on location and utility. The addition of the desuperheater water heating option increased the annual savings by an additional $332 to $478.

The annual energy cost values are presented in Figure 18 for the small office new construction GHP system without the desuperheater water heating option. The annual energy cost values are presented in Figure 19 for the small office new construction GHP system with the desuperheater water heating option added.

The annual savings from the installation provided a simple payback of 31 to 35 years and a net increase in life cycle costs. Economics for small office new construction installations both on an absolute basis and normalized per square foot are shown in Figure 20 and Figure 22.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 24 and the emissions with the addition of a desuperheater are shown in Figure 25. The installation of a GHP system in a small office new construction building reduces CO2 emissions by 10.7% to 12.4%, depending on location. The addition of a desuperheater reduces CO2 emissions by a further 2.7% to 2.8%. All other emissions would increase due to the increased electric consumption.

Figure 14: Annual Demand and Energy Values for a Small Office New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	55	138,340	7,413	51	167,125	0	4	-28,785	7,413
St. Cloud	54	143,369	6,540	51	168,733	0	3	-25,364	6,540
Minneapolis	55	145,332	6,260	51	169,434	0	4	-24,102	6,260

Figure 15: Annual Demand and Energy Values for a Small Office New Construction Building with Desuperheater included in the GHP System

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	55	138,340	7,413	50	162,016	0	5	-23,676	7,413
St. Cloud	54	143,369	6,540	49	163,444	0	5	-20,075	6,540
Minneapolis	55	145,332	6,260	50	164,056	0	5	-18,724	6,260

Figure 16: Annual Demand and Energy Values per Square Foot for a Small Office New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	4.2	10.6	0.57	4.0	12.8	0	0.3	-2.2	0.57
St. Cloud	4.2	11.0	0.50	3.9	13.0	0	0.3	-2.0	0.50
Minneapolis	4.2	11.2	0.48	4.0	13.0	0	0.3	-1.9	0.48

Figure 17: Annual Demand and Energy Values per Square Foot for a Small Office New Construction Building with Desuperheater included in the GHP System

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	4.2	10.6	0.57	3.8	12.5	0	0.4	-1.8	0.57
St. Cloud	4.2	11.0	0.50	3.8	12.6	0	0.4	-1.5	0.50
Minneapolis	4.2	11.2	0.48	3.8	12.6	0	0.4	-1.4	0.48

Figure 18: Annual Energy Charges and Savings for a Small Office New Construction Building

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 8,538	$ 7,314	$ 15,852	$ 10,472	$ -	$ 10,472	$ 5,380	34%
	Otter Tail Power	$ 10,265	$ 7,314	$ 17,578	$ 12,318	$ -	$ 12,318	$ 5,260	30%
	Xcel Energy	$ 9,902	$ 7,314	$ 17,215	$ 12,207	$ -	$ 12,207	$ 5,008	29%
St. Cloud	Minnesota Power	$ 8,866	$ 6,452	$ 15,319	$ 10,638	$ -	$ 10,638	$ 4,681	31%
	Otter Tail Power	$ 10,624	$ 6,452	$ 17,076	$ 12,433	$ -	$ 12,433	$ 4,643	27%
	Xcel Energy	$ 10,274	$ 6,452	$ 16,726	$ 12,374	$ -	$ 12,374	$ 4,352	26%
Minneapolis	Alliant Energy	$ 8,673	$ 6,176	$ 14,849	$ 9,985	$ -	$ 9,985	$ 4,863	33%
	Otter Tail Power	$ 10,764	$ 6,176	$ 16,940	$ 12,483	$ -	$ 12,483	$ 4,457	26%
	Xcel Energy	$ 10,373	$ 6,176	$ 16,550	$ 12,274	$ -	$ 12,274	$ 4,275	26%

Figure 19: Annual Energy Charges and Savings for a Small Office New Construction Building with Desuperheater included in the GHP System

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 8,538	$ 7,314	$ 15,852	$ 10,123	$ -	$ 10,123	$ 5,729	36%
	Otter Tail Power	$ 10,265	$ 7,314	$ 17,578	$ 11,954	$ -	$ 11,954	$ 5,625	32%
	Xcel Energy	$ 9,902	$ 7,314	$ 17,215	$ 11,754	$ -	$ 11,754	$ 5,461	32%
St. Cloud	Minnesota Power	$ 8,866	$ 6,452	$ 15,319	$ 10,263	$ -	$ 10,263	$ 5,056	33%
	Otter Tail Power	$ 10,624	$ 6,452	$ 17,076	$ 12,056	$ -	$ 12,056	$ 5,020	29%
	Xcel Energy	$ 10,274	$ 6,452	$ 16,726	$ 11,897	$ -	$ 11,897	$ 4,829	29%
Minneapolis	Alliant Energy	$ 8,673	$ 6,176	$ 14,849	$ 9,653	$ -	$ 9,653	$ 5,196	35%
	Otter Tail Power	$ 10,764	$ 6,176	$ 16,940	$ 12,099	$ -	$ 12,099	$ 4,840	29%
	Xcel Energy	$ 10,373	$ 6,176	$ 16,550	$ 11,840	$ -	$ 11,840	$ 4,709	28%

Figure 20: Economics of Conventional and GHP HVAC Systems for a Small Office New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 208,096	$ 3,473	$ 16,882	$ 416,536	$ 370,671	$ 3,395	$ 11,666	$ 443,602	$ 5,294	30.7	$ (27,066)	-6.5%
St. Cloud	$ 208,096	$ 3,473	$ 16,374	$ 412,039	$ 370,671	$ 3,395	$ 11,815	$ 445,391	$ 4,637	35.1	$ (33,352)	-8.1%
Minneapolis	$ 208,096	$ 3,473	$ 16,113	$ 409,424	$ 370,671	$ 3,395	$ 11,581	$ 442,584	$ 4,610	35.4	$ (33,160)	-8.1%

Figure 21: Economics of Conventional and GHP HVAC Systems for a Small Office New Construction Building, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 208,096	$ 3,473	$ 16,882	$ 416,536	$ 373,171	$ 3,395	$ 11,277	$ 441,442	$ 5,683	29.1	$ (24,906)	-6.0%
St. Cloud	$ 208,096	$ 3,473	$ 16,374	$ 412,039	$ 373,171	$ 3,395	$ 11,405	$ 442,978	$ 5,046	32.7	$ (30,939)	-7.5%
Minneapolis	$ 208,096	$ 3,473	$ 16,113	$ 409,424	$ 373,171	$ 3,395	$ 11,198	$ 440,490	$ 4,993	33.1	$ (31,066)	-7.6%

Figure 22: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small Office New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 16.00	$ 0.267	$ 1.30	$ 32.03	$ 28.50	$ 0.261	$ 0.90	$ 34.11	$ 0.41	30.7	$ (2.08)	-6.5%
St. Cloud	$ 16.00	$ 0.267	$ 1.26	$ 31.68	$ 28.50	$ 0.261	$ 0.91	$ 34.25	$ 0.36	35.1	$ (2.56)	-8.1%
Minneapolis	$ 16.00	$ 0.267	$ 1.24	$ 31.48	$ 28.50	$ 0.261	$ 0.89	$ 34.03	$ 0.35	35.4	$ (2.55)	-8.1%

Figure 23: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small Office New Construction Building, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 16.00	$ 0.267	$ 1.30	$ 32.03	$ 28.69	$ 0.261	$ 0.87	$ 33.94	$ 0.44	29.1	$ (1.91)	-6.0%
St. Cloud	$ 16.00	$ 0.267	$ 1.26	$ 31.68	$ 28.69	$ 0.261	$ 0.88	$ 34.06	$ 0.39	32.7	$ (2.38)	-7.5%
Minneapolis	$ 16.00	$ 0.267	$ 1.24	$ 31.48	$ 28.69	$ 0.261	$ 0.86	$ 33.87	$ 0.38	33.1	$ (2.39)	-7.6%

Figure 24: Annual Emissions Values for a Small Office New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	317,172	616	576	112	0.0063	318,353
	GHP	277,809	743	614	129	0.0074	278,664
	Reduction	39,363	-128	-37	-17	-0.0011	39,689
	% Change	-12.4%	20.7%	6.5%	14.9%	17.2%	-12.5%
St. Cloud	Conventional	315,261	638	587	115	0.0065	316,412
	GHP	280,482	750	620	130	0.0074	281,345
	Reduction	34,779	-112	-33	-15	-0.0009	35,067
	% Change	-11.0%	17.6%	5.6%	12.7%	14.7%	-11.1%
Minneapolis	Conventional	315,230	647	591	117	0.0066	316,373
	GHP	281,647	754	622	131	0.0075	282,514
	Reduction	33,583	-107	-31	-14	-0.0009	33,859
	% Change	-10.7%	16.5%	5.2%	11.9%	13.7%	-10.7%

Figure 25: Annual Emissions Values for a Small Office New Construction Building with Desuperheater included in the GHP System

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	317,172	616	576	112	0.0063	318,353
	GHP	269,316	721	595	125	0.0071	270,145
	Reduction	47,856	-105	-19	-13	-0.0009	48,208
	% Change	-15.1%	17.0%	3.2%	11.3%	13.6%	-15.1%
St. Cloud	Conventional	315,261	638	587	115	0.0065	316,412
	GHP	271,690	727	600	126	0.0072	272,526
	Reduction	43,571	-89	-13	-11	-0.0007	43,886
	% Change	-13.8%	13.9%	2.3%	9.2%	11.1%	-13.9%
Minneapolis	Conventional	315,230	647	591	117	0.0066	316,373
	GHP	272,707	730	602	127	0.0072	273,546
	Reduction	42,522	-83	-11	-10	-0.0007	42,826
	% Change	-13.5%	12.8%	1.9%	8.4%	10.1%	-13.5%

Figure 26: Annual Emissions Values per Square Foot for a Small Office New Construction Building

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	24	0.047	0.044	0.009	0.00048	24
	GHP	21	0.057	0.047	0.010	0.00057	21
	Reduction	3	-0.010	-0.003	-0.001	-0.00008	3
	% Change	-12.4%	20.7%	6.5%	14.9%	17.2%	-12.5%
St. Cloud	Conventional	24	0.049	0.045	0.009	0.00050	24
	GHP	22	0.058	0.048	0.010	0.00057	22
	Reduction	3	-0.009	-0.003	-0.001	-0.00007	3
	% Change	-11.0%	17.6%	5.6%	12.7%	14.7%	-11.1%
Minneapolis	Conventional	24	0.050	0.045	0.009	0.00050	24
	GHP	22	0.058	0.048	0.010	0.00057	22
	Reduction	3	-0.008	-0.002	-0.001	-0.00007	3
	% Change	-10.7%	16.5%	5.2%	11.9%	13.7%	-10.7%

Figure 27: Annual Emissions Values per Square Foot for a Small Office New Construction Building Building with Desuperheater included in the GHP System

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	24	0.047	0.044	0.009	0.00048	24
	GHP	21	0.055	0.046	0.010	0.00055	21
	Reduction	4	-0.008	-0.001	-0.001	-0.00007	4
	% Change	-15.1%	17.0%	3.2%	11.3%	13.6%	-15.1%
St. Cloud	Conventional	24	0.049	0.045	0.009	0.00050	24
	GHP	21	0.056	0.046	0.010	0.00055	21
	Reduction	3	-0.007	-0.001	-0.001	-0.00006	3
	% Change	-13.8%	13.9%	2.3%	9.2%	11.1%	-13.9%
Minneapolis	Conventional	24	0.050	0.045	0.009	0.00050	24
	GHP	21	0.056	0.046	0.010	0.00056	21
	Reduction	3	-0.006	-0.001	-0.001	-0.00005	3
	% Change	-13.5%	12.8%	1.9%	8.4%	10.1%	-13.5%

Figure 28: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Small Office New Construction Building

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	12	9.2	80%	68%	14.1	12.5	3.3	2.2
St. Cloud	12	9.6	80%	67%	14.1	12.3	3.3	2.2
Minneapolis	12	10.3	80%	67%	14.1	12.3	3.3	2.3

2.1.1.2 Small Office, Existing Building

The small office existing building with the conventional HVAC system had electrical demand and energy consumption values ranging from 68 to 71 kW and 170 to 185 MWh, depending on location. The small office existing building with the conventional HVAC system had natural gas requirements of 8,881 to 10,723 therms, depending on location.

The small office existing building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, a decrease of 4 to 5 kW summer peak demand, an increase of 29 to 33 kW winter peak demand, and an increase of 26 to 34 MWh, depending on location. Based on a cursory economic analysis, electric water heating was utilized in the GHP system. This allowed the gas consumption in the GHP case to be reduced to zero for all locations.

The demand and energy consumption values are presented in Figure 29 for the small office existing building GHP retrofit without the desuperheater water heating option. The demand and energy consumption values are presented in Figure 30 for the small office existing building GHP system with the desuperheater water heating option added.

The small office existing building with the conventional HVAC system had total annual energy costs from $19,767 to $23,131, depending on location and utility. The small office existing building with the GHP HVAC system had higher electrical costs but no natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $6,730 to $8,318, or 31% to 39% of the conventional HVAC system energy costs, depending on location and utility. The addition of the desuperheater water heating option increased the annual savings by an additional $332 to $478.

The annual energy cost values are presented in Figure 33 for the small office existing building GHP system without the desuperheater water heating option. The annual energy cost values are presented in Figure 34 for the small office existing building GHP system with the desuperheater water heating option added.

The annual savings from the installation provided a simple payback of 23 to 27 years and a net increase in life cycle costs. Economics for small office existing building retrofit installations both on an absolute basis and normalized per square foot are shown in Figure 35 and Figure 37.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 39, and the emissions with the addition of a desuperheater are shown in Figure 40. The installation of a GHP system in a small office new construction building reduces CO2 emissions by 14.8% to 16.9%, depending on location. The addition of a desuperheater reduces CO2 emissions by a further 2.1% to 2.2%. All other emissions would increase due to the increased electric consumption.

Figure 29: Annual Demand and Energy Values for a Small Office Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	68	170,395	10,723	64	204,576	0	4	-34,181	10,723
St. Cloud	71	182,051	9,098	66	209,463	0	5	-27,412	9,098
Minneapolis	71	184,512	8,881	66	210,829	0	5	-26,317	8,881

Figure 30: Annual Demand and Energy Values for a Small Office Existing Building Retrofit with Desuperheater included in the GHP System

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	68	170,395	10,723	62	199,467	0	6	-29,072	10,723
St. Cloud	71	182,051	9,098	65	204,174	0	6	-22,123	9,098
Minneapolis	71	184,512	8,881	64	205,451	0	7	-20,939	8,881

Figure 31: Annual Demand and Energy Values per Square Foot for a Small Office Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	5.2	13.1	0.82	4.9	15.7	0	0.3	-2.6	0.82
St. Cloud	5.5	14.0	0.70	5.1	16.1	0	0.4	-2.1	0.70
Minneapolis	5.5	14.2	0.68	5.1	16.2	0	0.4	-2.0	0.68

Figure 32: Annual Demand and Energy Values per Square Foot for a Small Office Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	5.2	13.1	0.82	4.8	15.3	0	0.5	-2.2	0.82
St. Cloud	5.5	14.0	0.70	5.0	15.7	0	0.5	-1.7	0.70
Minneapolis	5.5	14.2	0.68	5.0	15.8	0	0.5	-1.6	0.68

Figure 33: Annual Energy Charges and Savings for a Small Office Existing Building Retrofit

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 10,518	$ 10,579	$ 21,098	$ 12,779	$ -	$ 12,779	$ 8,318	39%
	Otter Tail Power	$ 12,552	$ 10,579	$ 23,131	$ 14,990	$ -	$ 14,990	$ 8,141	35%
	Xcel Energy	$ 12,198	$ 10,579	$ 22,777	$ 14,844	$ -	$ 14,844	$ 7,934	35%
St. Cloud	Minnesota Power	$ 11,274	$ 8,976	$ 20,250	$ 13,183	$ -	$ 13,183	$ 7,067	35%
	Otter Tail Power	$ 13,383	$ 8,976	$ 22,359	$ 15,339	$ -	$ 15,339	$ 7,021	31%
	Xcel Energy	$ 13,087	$ 8,976	$ 22,064	$ 15,329	$ -	$ 15,329	$ 6,734	31%
Minneapolis	Alliant Energy	$ 11,005	$ 8,762	$ 19,767	$ 12,423	$ -	$ 12,423	$ 7,344	37%
	Otter Tail Power	$ 13,559	$ 8,762	$ 22,321	$ 15,436	$ -	$ 15,436	$ 6,885	31%
	Xcel Energy	$ 13,201	$ 8,762	$ 21,963	$ 15,233	$ -	$ 15,233	$ 6,730	31%

Figure 34: Annual Energy Charges and Savings for a Small Office Existing Building Retrofit with Desuperheater included in the GHP System

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 10,518	$ 10,579	$ 21,098	$ 12,430	$ -	$ 12,430	$ 8,667	41%
	Otter Tail Power	$ 12,552	$ 10,579	$ 23,131	$ 14,626	$ -	$ 14,626	$ 8,505	37%
	Xcel Energy	$ 12,198	$ 10,579	$ 22,777	$ 14,391	$ -	$ 14,391	$ 8,387	37%
St. Cloud	Minnesota Power	$ 11,274	$ 8,976	$ 20,250	$ 12,809	$ -	$ 12,809	$ 7,441	37%
	Otter Tail Power	$ 13,383	$ 8,976	$ 22,359	$ 14,961	$ -	$ 14,961	$ 7,398	33%
	Xcel Energy	$ 13,087	$ 8,976	$ 22,064	$ 14,852	$ -	$ 14,852	$ 7,212	33%
Minneapolis	Alliant Energy	$ 11,005	$ 8,762	$ 19,767	$ 12,091	$ -	$ 12,091	$ 7,676	39%
	Otter Tail Power	$ 13,559	$ 8,762	$ 22,321	$ 15,052	$ -	$ 15,052	$ 7,268	33%
	Xcel Energy	$ 13,201	$ 8,762	$ 21,963	$ 14,800	$ -	$ 14,800	$ 7,164	33%

Figure 35: Economics of Conventional and GHP HVAC Systems for a Small Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 221,102	$ 3,473	$ 22,335	$ 489,519	$ 409,689	$ 3,395	$ 14,204	$ 513,047	$ 8,209	23.0	$ (23,528)	-4.8%
St. Cloud	$ 221,102	$ 3,473	$ 21,558	$ 483,170	$ 409,689	$ 3,395	$ 14,617	$ 517,995	$ 7,019	26.9	$ (34,825)	-7.2%
Minneapolis	$ 221,102	$ 3,473	$ 21,350	$ 481,083	$ 409,689	$ 3,395	$ 14,364	$ 514,963	$ 7,064	26.7	$ (33,880)	-7.0%

Figure 36: Economics of Conventional and GHP HVAC Systems for a Small Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 221,102	$ 3,473	$ 22,335	$ 416,536	$ 412,189	$ 3,395	$ 13,816	$ 510,887	$ 8,598	22.2	$ (94,351)	-22.7%
St. Cloud	$ 221,102	$ 3,473	$ 21,558	$ 412,039	$ 412,189	$ 3,395	$ 14,207	$ 515,581	$ 7,428	25.7	$ (103,542)	-25.1%
Minneapolis	$ 221,102	$ 3,473	$ 21,350	$ 409,424	$ 412,189	$ 3,395	$ 13,981	$ 512,869	$ 7,447	25.7	$ (103,445)	-25.3%

Figure 37: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 17.00	$ 0.267	$ 1.72	$ 37.64	$ 31.50	$ 0.261	$ 1.09	$ 39.45	$ 0.63	23.0	$ (1.81)	-4.8%
St. Cloud	$ 17.00	$ 0.267	$ 1.66	$ 37.15	$ 31.50	$ 0.261	$ 1.12	$ 39.83	$ 0.54	26.9	$ (2.68)	-7.2%
Minneapolis	$ 17.00	$ 0.267	$ 1.64	$ 36.99	$ 31.50	$ 0.261	$ 1.10	$ 39.59	$ 0.54	26.7	$ (2.60)	-7.0%

Figure 38: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 17.00	$ 0.267	$ 1.72	$ 37.64	$ 31.69	$ 0.261	$ 1.06	$ 39.28	$ 0.66	22.2	$ (1.64)	-4.4%
St. Cloud	$ 17.00	$ 0.267	$ 1.66	$ 37.15	$ 31.69	$ 0.261	$ 1.09	$ 39.64	$ 0.57	25.7	$ (2.49)	-6.7%
Minneapolis	$ 17.00	$ 0.267	$ 1.64	$ 36.99	$ 31.69	$ 0.261	$ 1.07	$ 39.43	$ 0.57	25.7	$ (2.44)	-6.6%

Figure 39: Annual Emissions Values for a Small Office Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	409,398	758	725	139	0.0078	410,954
	GHP	340,063	910	751	158	0.0090	341,109
	Reduction	69,334	-151	-27	-18	-0.0012	69,844
	% Change	-16.9%	20.0%	3.7%	13.2%	15.8%	-17.0%
St. Cloud	Conventional	409,655	810	752	147	0.0082	411,167
	GHP	348,187	932	769	162	0.0092	349,258
	Reduction	61,469	-121	-17	-14	-0.0010	61,909
	% Change	-15.0%	15.0%	2.2%	9.8%	11.8%	-15.1%
Minneapolis	Conventional	411,193	821	759	149	0.0083	412,704
	GHP	350,457	938	774	163	0.0093	351,536
	Reduction	60,736	-117	-15	-14	-0.0009	61,168
	% Change	-14.8%	14.2%	1.9%	9.2%	11.2%	-14.8%

Figure 40: Annual Emissions Values for a Small Office Existing Building Retrofit with Desuperheater included in the GHP System

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	409,398	758	725	139	0.0078	410,954
	GHP	331,570	887	733	154	0.0088	341,109
	Reduction	77,827	-129	-8	-14	-0.0010	69,844
	% Change	-19.0%	17.0%	1.1%	10.4%	12.9%	-17.0%
St. Cloud	Conventional	409,655	810	752	147	0.0082	410,954
	GHP	339,395	908	750	157	0.0090	341,109
	Reduction	70,261	-98	3	-10	-0.0007	69,844
	% Change	-17.2%	12.1%	-0.3%	7.0%	9.0%	-17.0%
Minneapolis	Conventional	411,193	821	759	149	0.0083	410,954
	GHP	341,518	914	754	158	0.0090	341,109
	Reduction	69,676	-93	5	-10	-0.0007	69,844
	% Change	-16.9%	11.3%	-0.7%	6.4%	8.3%	-17.0%

Figure 41: Annual Emissions Values per Square Foot for a Small Office Existing Building Retrofit

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	31	0.058	0.056	0.011	0.00060	32
	GHP	26	0.070	0.058	0.012	0.00069	26
	Reduction	5	-0.012	-0.002	-0.001	-0.00009	5
	% Change	-16.9%	20.0%	3.7%	13.2%	15.8%	-17.0%
St. Cloud	Conventional	31	0.062	0.058	0.011	0.00063	32
	GHP	27	0.072	0.059	0.012	0.00071	27
	Reduction	5	-0.009	-0.001	-0.001	-0.00007	5
	% Change	-15.0%	15.0%	2.2%	9.8%	11.8%	-15.1%
Minneapolis	Conventional	32	0.063	0.058	0.011	0.00064	32
	GHP	27	0.072	0.060	0.013	0.00071	27
	Reduction	5	-0.009	-0.001	-0.001	-0.00007	5
	% Change	-14.8%	14.2%	1.9%	9.2%	11.2%	-14.8%

Figure 42: Annual Emissions Values per Square Foot for a Small Office Existing Building Retrofit with Desuperheater included in the GHP System

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	31	0.058	0.056	0.011	0.00060	32
	GHP	25	0.068	0.056	0.012	0.00067	26
	Reduction	6	-0.010	-0.001	-0.001	-0.00008	5
	% Change	-19.0%	17.0%	1.1%	10.4%	12.9%	-17.0%
St. Cloud	Conventional	31	0.062	0.058	0.011	0.00063	32
	GHP	26	0.070	0.058	0.012	0.00069	26
	Reduction	5	-0.008	0.000	-0.001	-0.00006	5
	% Change	-17.2%	12.1%	-0.3%	7.0%	9.0%	-17.0%
Minneapolis	Conventional	32	0.063	0.058	0.011	0.00064	32
	GHP	26	0.070	0.058	0.012	0.00070	26
	Reduction	5	-0.007	0.000	-0.001	-0.00005	5
	% Change	-16.9%	11.3%	-0.7%	6.4%	8.3%	-17.0%

Figure 43: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Small Office Existing Building Retrofit

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	12	9.1	80%	68%	14.1	12.5	3.3	2.4
St. Cloud	12	9.4	80%	68%	14.1	12.3	3.3	2.2
Minneapolis	12	10.2	80%	68%	14.1	12.2	3.3	2.3

** The average efficiencies of systems in existing buildings shown in Figure 43 are higher than the average efficiencies of systems in new construction buildings shown in Figure 28 due to the difference in construction. The higher insulation levels used in new construction reduce the operating load on the HVAC system, causing the system to run in lower-efficiency cycling patterns more often.*

2.1.1.3 Large Office, New Construction

The large office new construction building with the conventional HVAC system had electrical demand and energy consumption values ranging from 273 to 286 kW and 713 to 765 MWh, depending on location. The large office new construction building with the conventional HVAC system had natural gas requirements of 24,638 to 28,761 therms, depending on location.

The large office new construction building with the GHP HVAC system had higher electrical demand and energy consumption values, an increase of 16 to 18 kW summer peak demand, an increase of 98 to 122 kW winter peak demand, and an increase of 132 to 151 MWh, depending on location. Based on a cursory economic analysis, electric water heating was not utilized in the GHP system.

The demand and energy consumption values are presented in Figure 44 for the large office new construction GHP retrofit.

The large office new construction building with the conventional HVAC system had total annual energy costs from $69,626 to $79,510, depending on location and utility. The large office new construction building with the GHP HVAC system had higher electrical costs but lower natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $14,272 to $18,553, or 18% to 26% of the conventional HVAC system energy costs, depending on location and utility.

The annual savings from the installation provided a simple payback of 17 to 20 years and a net decrease in life cycle costs. Economics for large office new construction installations both on an absolute basis and normalized per square foot are shown in Figure 47 and Figure 48.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 49. The installation of a GHP system in a large office new construction building reduces CO2 emissions by 3.2% to 4.2%, depending on location. All other emissions would increase due to the increased electric consumption.

Figure 44: Annual Demand and Energy Values for a Large Office New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	273	713,143	28,761	291	864,490	1,920	-18	-151,347	26,841
St. Cloud	278	754,653	25,212	295	886,603	1,812	-17	-131,950	23,400
Minneapolis	286	765,248	24,638	302	896,950	1,728	-16	-131,702	22,910

Figure 45: Annual Demand and Energy Values per Square Foot for a Large Office New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	3.6	9.5	0.38	3.9	11.5	0	-0.2	-2.0	0.36
St. Cloud	3.7	10.1	0.34	3.9	11.8	0	-0.2	-1.8	0.31
Minneapolis	3.8	10.2	0.33	4.0	11.9	0	-0.2	-1.8	0.31

Figure 46: Annual Energy Charges and Savings for a Large Office New Construction Building

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 44,113	$ 28,376	$ 72,488	$ 52,990	$ 1,894	$ 54,884	$ 17,605	24%
	Otter Tail Power	$ 42,275	$ 28,376	$ 70,651	$ 50,204	$ 1,894	$ 52,098	$ 18,553	26%
	Xcel Energy	$ 51,134	$ 28,376	$ 79,510	$ 60,645	$ 1,894	$ 62,540	$ 16,970	21%
St. Cloud	Minnesota Power	$ 46,799	$ 24,874	$ 71,673	$ 54,485	$ 1,788	$ 56,272	$ 15,401	21%
	Otter Tail Power	$ 44,840	$ 24,874	$ 69,714	$ 51,749	$ 1,788	$ 53,536	$ 16,178	23%
	Xcel Energy	$ 54,232	$ 24,874	$ 79,106	$ 62,478	$ 1,788	$ 64,266	$ 14,841	19%
Minneapolis	Alliant Energy	$ 52,339	$ 24,308	$ 76,647	$ 60,146	$ 1,705	$ 61,851	$ 14,795	19%
	Otter Tail Power	$ 45,318	$ 24,308	$ 69,626	$ 52,138	$ 1,705	$ 53,843	$ 15,783	23%
	Xcel Energy	$ 54,842	$ 24,308	$ 79,150	$ 63,173	$ 1,705	$ 64,878	$ 14,272	18%

Figure 47: Economics of Conventional and GHP HVAC Systems for a Large Office New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 1,801,440	$ 11,109	$ 74,216	$ 2,382,494	$ 2,139,210	$ 8,932	$ 56,507	$ 2,300,844	$ 19,886	17.0	$ 81,650	3.4%
St. Cloud	$ 1,801,440	$ 11,109	$ 73,498	$ 2,380,375	$ 2,139,210	$ 8,932	$ 58,025	$ 2,319,233	$ 17,650	19.2	$ 61,142	2.6%
Minneapolis	$ 1,801,440	$ 11,109	$ 75,141	$ 2,401,119	$ 2,139,210	$ 8,932	$ 60,191	$ 2,345,347	$ 17,127	19.7	$ 55,772	2.3%

Figure 48: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large Office New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 24.00	$ 0.148	$ 0.99	$ 31.74	$ 28.50	$ 0.119	$ 0.75	$ 30.65	$ 0.26	17.0	$ 1.09	3.4%
St. Cloud	$ 24.00	$ 0.148	$ 0.98	$ 31.71	$ 28.50	$ 0.119	$ 0.77	$ 30.90	$ 0.24	19.2	$ 0.81	2.6%
Minneapolis	$ 24.00	$ 0.148	$ 1.00	$ 31.99	$ 28.50	$ 0.119	$ 0.80	$ 31.25	$ 0.23	19.7	$ 0.74	2.3%

Figure 49: Annual Emissions Values for a Large Office New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,523,810	3,173	2,901	571	0.0321	1,529,293
	GHP	1,459,615	3,845	3,194	668	0.0381	1,464,159
	Reduction	64,195	-671	-293	-97	-0.0060	65,135
	% Change	-4.2%	21.2%	10.1%	16.9%	18.6%	-4.3%
St. Cloud	Conventional	1,551,058	3,358	3,019	601	0.0338	1,556,527
	GHP	1,495,102	3,943	3,274	685	0.0391	1,499,752
	Reduction	55,956	-585	-255	-84	-0.0052	56,775
	% Change	-3.6%	17.4%	8.5%	14.0%	15.4%	-3.6%
Minneapolis	Conventional	1,561,917	3,405	3,052	609	0.0343	1,567,404
	GHP	1,511,313	3,989	3,311	693	0.0395	1,516,011
	Reduction	50,604	-584	-259	-84	-0.0052	51,393
	% Change	-3.2%	17.2%	8.5%	13.9%	15.2%	-3.3%

Figure 50: Annual Emissions Values per Square Foot for a Large Office New Construction Building

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	20	0.042	0.039	0.008	0.00043	20
	GHP	19	0.051	0.043	0.009	0.00051	20
	Reduction	1	-0.009	-0.004	-0.001	-0.00008	1
	% Change	-4.2%	21.2%	10.1%	16.9%	18.6%	-4.3%
St. Cloud	Conventional	21	0.045	0.040	0.008	0.00045	21
	GHP	20	0.053	0.044	0.009	0.00052	20
	Reduction	1	-0.008	-0.003	-0.001	-0.00007	1
	% Change	-3.6%	17.4%	8.5%	14.0%	15.4%	-3.6%
Minneapolis	Conventional	21	0.045	0.041	0.008	0.00046	21
	GHP	20	0.053	0.044	0.009	0.00053	20
	Reduction	1	-0.008	-0.003	-0.001	-0.00007	1
	% Change	-3.2%	17.2%	8.5%	13.9%	15.2%	-3.3%

Figure 51: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Large Office New Construction Building

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	16.7	15.4	85%	75%	14.1	12.3	3.3	2.3
St. Cloud	16.7	15.5	85%	75%	14.1	12.2	3.3	2.2
Minneapolis	16.7	15.9	85%	74%	14.1	12.1	3.3	2.2

2.1.1.4 Large Office, Existing Building

The large office existing building with the conventional HVAC system had electrical demand and energy consumption values ranging from 350 to 365 kW and 902 to 968 MWh, depending on location. The large office existing building with the conventional HVAC system had natural gas requirements of 31,396 to 38,064 therms, depending on location.

The large office existing building with the GHP HVAC system had higher electrical demand and energy consumption values, an increase of 21 to 24 kW summer peak demand, an increase of 128 to 149 kW winter peak demand, and an increase of 163 to 192 MWh, depending on location. Based on a cursory economic analysis, electric water heating was not utilized in the GHP system.

The demand and energy consumption values are presented in Figure 52 for the large office existing building GHP retrofit.

The large office existing building with the conventional HVAC system had total annual energy costs from $87,419 to $102,413, depending on location and utility. The large office existing building with the GHP HVAC system had higher electrical costs but lower natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $18,791 to $25,462, or 19% to 28% of the conventional HVAC system energy costs, depending on location and utility.

The annual savings from the installation provided a simple payback of 18 to 22 years and a net increase in life cycle costs. Economics for large office existing building retrofit installations both on an absolute basis and normalized per square foot are shown in Figure 55 and Figure 56.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 57. The installation of a GHP system in a large office existing building reduces CO_2 emissions by 3.8% to 5.5%, depending on location. All other emissions would increase due to the increased electric consumption.

Figure 52: Annual Demand and Energy Values for a Large Office Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	350	902,099	38,064	374	1,093,608	1,920	-24	-191,509	36,144
St. Cloud	360	954,552	31,396	384	1,118,840	1,812	-24	-164,288	29,584
Minneapolis	365	967,632	31,895	386	1,130,397	1,728	-21	-162,765	30,167

Figure 53: Annual Demand and Energy Values per Square Foot for a Large Office Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	4.7	12.0	0.51	5.0	14.6	0	-0.3	-2.6	0.48
St. Cloud	4.8	12.7	0.42	5.1	14.9	0	-0.3	-2.2	0.39
Minneapolis	4.9	12.9	0.42	5.1	15.1	0	-0.3	-2.2	0.40

Figure 54: Annual Energy Charges and Savings for a Large Office Existing Building Retrofit

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 55,871	$ 37,554	$ 93,425	$ 67,180	$ 1,894	$ 69,074	$ 24,351	26%
	Otter Tail Power	$ 53,164	$ 37,554	$ 90,718	$ 63,362	$ 1,894	$ 65,256	$ 25,462	28%
	Xcel Energy	$ 64,859	$ 37,554	$ 102,413	$ 77,011	$ 1,894	$ 78,905	$ 23,508	23%
St. Cloud	Minnesota Power	$ 59,288	$ 30,975	$ 90,264	$ 68,936	$ 1,788	$ 70,724	$ 19,540	22%
	Otter Tail Power	$ 56,444	$ 30,975	$ 87,419	$ 65,225	$ 1,788	$ 67,012	$ 20,407	23%
	Xcel Energy	$ 68,823	$ 30,975	$ 99,798	$ 79,219	$ 1,788	$ 81,007	$ 18,791	19%
Minneapolis	Alliant Energy	$ 66,389	$ 31,468	$ 97,857	$ 76,107	$ 1,705	$ 77,812	$ 20,044	20%
	Otter Tail Power	$ 57,057	$ 31,468	$ 88,524	$ 65,630	$ 1,705	$ 67,335	$ 21,189	24%
	Xcel Energy	$ 69,582	$ 31,468	$ 101,050	$ 79,969	$ 1,705	$ 81,674	$ 19,376	19%

Figure 55: Economics of Conventional and GHP HVAC Systems for a Large Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 1,876,500	$ 11,109	$ 95,518	$ 2,695,863	$ 2,364,390	$ 8,932	$ 71,078	$ 2,700,676	$ 26,617	18.3	$ (4,813)	-0.2%
St. Cloud	$ 1,876,500	$ 11,109	$ 92,494	$ 2,671,806	$ 2,364,390	$ 8,932	$ 72,914	$ 2,722,880	$ 21,756	22.4	$ (51,075)	-1.9%
Minneapolis	$ 1,876,500	$ 11,109	$ 95,810	$ 2,710,646	$ 2,364,390	$ 8,932	$ 75,607	$ 2,755,307	$ 22,380	21.8	$ (44,660)	-1.6%

Figure 56: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large Office Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 25.00	$ 0.148	$ 1.27	$ 35.92	$ 31.50	$ 0.119	$ 0.95	$ 35.98	$ 0.35	18.3	$ (0.06)	-0.2%
St. Cloud	$ 25.00	$ 0.148	$ 1.23	$ 35.60	$ 31.50	$ 0.119	$ 0.97	$ 36.28	$ 0.29	22.4	$ (0.68)	-1.9%
Minneapolis	$ 25.00	$ 0.148	$ 1.28	$ 36.11	$ 31.50	$ 0.119	$ 1.01	$ 36.71	$ 0.30	21.8	$ (0.59)	-1.6%

Figure 57: Annual Emissions Values for a Large Office Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,947,355	4,014	3,686	724	0.0407	1,954,399
	GHP	1,840,473	4,864	4,035	845	0.0482	1,846,189
	Reduction	106,882	-850	-349	-121	-0.0075	108,210
	% Change	-5.5%	21.2%	9.5%	16.7%	18.5%	-5.5%
St. Cloud	Conventional	1,956,099	4,247	3,813	760	0.0428	1,962,986
	GHP	1,881,145	4,976	4,127	864	0.0493	1,886,984
	Reduction	74,954	-729	-313	-105	-0.0065	76,002
	% Change	-3.8%	17.2%	8.2%	13.8%	15.1%	-3.9%
Minneapolis	Conventional	1,983,713	4,305	3,866	770	0.0434	1,990,698
	GHP	1,899,368	5,027	4,168	873	0.0498	1,905,260
	Reduction	84,345	-722	-302	-103	-0.0064	85,438
	% Change	-4.3%	16.8%	7.8%	13.4%	14.7%	-4.3%

Figure 58: Annual Emissions Values per Square Foot for a Large Office Existing Building Retrofit

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	26	0.053	0.049	0.010	0.00054	26
	GHP	25	0.065	0.054	0.011	0.00064	25
	Reduction	1	-0.011	-0.005	-0.002	-0.00010	1
	% Change	-5.5%	21.2%	9.5%	16.7%	18.5%	-5.5%
St. Cloud	Conventional	26	0.057	0.051	0.010	0.00057	26
	GHP	25	0.066	0.055	0.012	0.00066	25
	Reduction	1	-0.010	-0.004	-0.001	-0.00009	1
	% Change	-3.8%	17.2%	8.2%	13.8%	15.1%	-3.9%
Minneapolis	Conventional	26	0.057	0.052	0.010	0.00058	27
	GHP	25	0.067	0.056	0.012	0.00066	25
	Reduction	1	-0.010	-0.004	-0.001	-0.00009	1
	% Change	-4.3%	16.8%	7.8%	13.4%	14.7%	-4.3%

Figure 59: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Large Office Existing Building Retrofit

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	16.7	14.8	85%	75%	14.1	12.3	3.3	2.5
St. Cloud	16.7	15.0	85%	75%	14.1	12.2	3.3	2.2
Minneapolis	16.7	15.5	85%	75%	14.1	12.1	3.3	2.3

** The average efficiencies of systems in existing buildings shown in Figure 59 are higher than the average efficiencies of systems in new construction buildings shown in Figure 51 due to the difference in construction. The higher insulation levels used in new construction reduce the operating load on the HVAC system, causing the system to run in lower-efficiency cycling patterns more often.*

2.1.2 Institutional Results

Institutional buildings were analyzed using building models for small and large schools. The small school conventional system is a VAV system with an air-cooled chiller with a 12.0 EER and a boiler with 85% rated efficiency for the cooling and heating, respectively. The large school conventional system is a VAV system with a water-cooled chiller with a 20.8 EER and a boiler with 85% rated efficiency for the cooling and heating, respectively. The comparisons between these systems and the GHP systems are detailed below.

2.1.2.1 Small School, New Construction

The small school new construction building with the conventional HVAC system had electrical demand and energy consumption values ranging from 167 to 187 kW and 416 to 446 MWh, depending on location. The small school new construction building with the conventional HVAC system had natural gas requirements of 25,423 to 29,617 therms, depending on location.

The small school new construction building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, a decrease of 3 to 6 kW in summer peak demand, an increase of 79 to 107 kW winter peak demand, and an increase of 40 to 58 MWh, depending on location. Based on a cursory economic analysis, electric water heating was not utilized in the GHP system.

The demand and energy consumption values are presented in Figure 60 for the small school new construction GHP retrofit.

The small school new construction building with the conventional HVAC system had total annual energy costs from $54,291 to $62,187, depending on location and utility. The small school new construction building with the GHP HVAC system had higher electrical costs but lower natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $12,047 to $15,890, or 20% to 28% of the conventional HVAC system energy costs, depending on location and utility.

The annual savings from the installation provided a simple payback of 16 to 19 years and a net decrease in life cycle costs. Economics for small school new construction installations both on an absolute basis and normalized per square foot are shown in Figure 63 and Figure 64.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 65. The installation of a GHP system in a small school new construction building reduces CO2 emissions by 10.7% to 13.3%, depending on location. All other emissions would increase due to the increased electric consumption.

Figure 60: Annual Demand and Energy Values for a Small School New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	167	416,169	29,617	164	473,843	9,737	3	-57,674	19,880
St. Cloud	180	436,106	26,491	175	476,223	9,175	5	-40,117	17,316
Minneapolis	187	446,072	25,423	181	497,547	8,726	6	-51,475	16,697

Figure 61: Annual Demand and Energy Values per Square Foot for a Small School New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.4	6.0	0.43	2.4	6.9	0	0.0	-0.8	0.29
St. Cloud	2.6	6.3	0.38	2.5	6.9	0	0.1	-0.6	0.25
Minneapolis	2.7	6.5	0.37	2.6	7.2	0	0.1	-0.7	0.24

Figure 62: Annual Energy Charges and Savings for a Small School New Construction Building

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 26,868	$ 29,220	$ 56,088	$ 30,591	$ 9,607	$ 40,198	$ 15,890	28%
	Otter Tail Power	$ 30,085	$ 29,220	$ 59,305	$ 34,200	$ 9,607	$ 43,806	$ 15,499	26%
	Xcel Energy	$ 32,967	$ 29,220	$ 62,187	$ 38,259	$ 9,607	$ 47,866	$ 14,321	23%
St. Cloud	Minnesota Power	$ 28,155	$ 26,136	$ 54,291	$ 30,745	$ 9,052	$ 39,797	$ 14,494	27%
	Otter Tail Power	$ 31,507	$ 26,136	$ 57,643	$ 34,369	$ 9,052	$ 43,421	$ 14,222	25%
	Xcel Energy	$ 35,061	$ 26,136	$ 61,197	$ 39,207	$ 9,052	$ 48,259	$ 12,939	21%
Minneapolis	Alliant Energy	$ 33,448	$ 25,082	$ 58,530	$ 37,406	$ 8,609	$ 46,016	$ 12,515	21%
	Otter Tail Power	$ 32,218	$ 25,082	$ 57,301	$ 35,891	$ 8,609	$ 44,500	$ 12,801	22%
	Xcel Energy	$ 35,824	$ 25,082	$ 60,907	$ 40,251	$ 8,609	$ 48,860	$ 12,047	20%

Figure 63: Economics of Conventional and GHP HVAC Systems for a Small School New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 1,658,736	$ 20,306	$ 59,193	$ 2,201,302	$ 1,969,749	$ 16,104	$ 43,956	$ 2,101,371	$ 19,439	16.0	$ 99,931	4.5%
St. Cloud	$ 1,658,736	$ 20,306	$ 57,711	$ 2,189,247	$ 1,969,749	$ 16,104	$ 43,826	$ 2,100,831	$ 18,087	17.2	$ 88,416	4.0%
Minneapolis	$ 1,658,736	$ 20,306	$ 58,913	$ 2,205,607	$ 1,969,749	$ 16,104	$ 46,458	$ 2,133,207	$ 16,656	18.7	$ 72,400	3.3%

Figure 64: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small School New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 24.00	$ 0.294	$ 0.86	$ 31.85	$ 28.50	$ 0.233	$ 0.64	$ 30.40	$ 0.28	16.0	$ 1.45	4.5%
St. Cloud	$ 24.00	$ 0.294	$ 0.84	$ 31.68	$ 28.50	$ 0.233	$ 0.63	$ 30.40	$ 0.26	17.2	$ 1.28	4.0%
Minneapolis	$ 24.00	$ 0.294	$ 0.85	$ 31.91	$ 28.50	$ 0.233	$ 0.67	$ 30.87	$ 0.24	18.7	$ 1.05	3.3%

Figure 65: Annual Emissions Values for a Small School New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,040,226	1,853	1,819	343	0.0191	1,044,245
	GHP	902,214	2,108	1,836	373	0.0211	905,259
	Reduction	138,012	-255	-17	-30	-0.0020	138,986
	% Change	-13.3%	13.8%	0.9%	8.6%	10.7%	-13.3%
St. Cloud	Conventional	1,036,590	1,941	1,861	356	0.0199	1,040,512
	GHP	899,558	2,118	1,839	374	0.0212	902,580
	Reduction	137,032	-177	22	-18	-0.0013	137,932
	% Change	-13.2%	9.1%	-1.2%	5.1%	6.7%	-13.3%
Minneapolis	Conventional	1,040,592	1,985	1,887	363	0.0203	1,044,496
	GHP	929,722	2,213	1,913	390	0.0221	932,824
	Reduction	110,869	-228	-25	-27	-0.0018	111,672
	% Change	-10.7%	11.5%	1.3%	7.5%	9.1%	-10.7%

Figure 66: Annual Emissions Values per Square Foot for a Small School New Construction Building

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	15	0.027	0.026	0.005	0.00028	15
	GHP	13	0.030	0.027	0.005	0.00031	13
	Reduction	2	-0.004	0.000	0.000	-0.00003	2
	% Change	-13.3%	13.8%	0.9%	8.6%	10.7%	-13.3%
St. Cloud	Conventional	15	0.028	0.027	0.005	0.00029	15
	GHP	13	0.031	0.027	0.005	0.00031	13
	Reduction	2	-0.003	0.000	0.000	-0.00002	2
	% Change	-13.2%	9.1%	-1.2%	5.1%	6.7%	-13.3%
Minneapolis	Conventional	15	0.029	0.027	0.005	0.00029	15
	GHP	13	0.032	0.028	0.006	0.00032	13
	Reduction	2	-0.003	0.000	0.000	-0.00003	2
	% Change	-10.7%	11.5%	1.3%	7.5%	9.1%	-10.7%

Figure 67: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Small School New Construction Building

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	12	9.4	85%	76%	14.1	12.4	3.3	2.0
St. Cloud	12	9.7	85%	76%	14.1	12.4	3.3	2.0
Minneapolis	12	10.5	85%	76%	14.1	12.3	3.3	1.9

2.1.2.2 Small School, Existing Building

The small school existing building with the conventional HVAC system had electrical demand and energy consumption values ranging from 201 to 221 kW and 516 to 551 MWh, depending on location. The small school existing building with the conventional HVAC system had natural gas requirements of 28,759 to 34,989 therms, depending on location.

The small school existing building with the GHP HVAC system had lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, a decrease of 3 to 6 kW in summer peak demand, an increase of 103 to 118 kW winter peak demand, and an increase of 47 to 77 MWh, depending on location. Based on a cursory economic analysis, electric water heating was not utilized in the GHP system.

The demand and energy consumption values are presented in Figure 68 for the small school existing building GHP retrofit.

The small school existing building with the conventional HVAC system had total annual energy costs from $63,472 to $74,806, depending on location and utility. The small school existing building with the GHP HVAC system had higher electrical costs but lower natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $14,757 to $19,959, or 20% to 29% of the conventional HVAC system energy costs, depending on location and utility.

The annual savings from the installation provided a simple payback of 13 to 16 years and a net decrease in life cycle costs. Economics for small school existing building retrofit installations both on an absolute basis and normalized per square foot are shown in Figure 71 and Figure 72.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 73. The installation of a GHP system in a small school existing building reduces CO2 emissions by 10.4% to 13.3%, depending on location. All other emissions would increase due to the increased electric consumption.

Figure 68: Annual Demand and Energy Values for a Small School Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	201	516,434	34,989	198	593,181	9,737	3	-76,747	25,252
St. Cloud	216	538,793	29,077	211	586,148	9,175	5	-47,355	19,902
Minneapolis	221	550,976	28,759	215	614,149	8,726	6	-63,173	20,033

Figure 69: Annual Demand and Energy Values per Square Foot for a Small School Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.9	7.5	0.51	2.9	8.6	0	0.0	-1.1	0.37
St. Cloud	3.1	7.8	0.42	3.1	8.5	0	0.1	-0.7	0.29
Minneapolis	3.2	8.0	0.42	3.1	8.9	0	0.1	-0.9	0.29

Figure 70: Annual Energy Charges and Savings for a Small School Existing Building Retrofit

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 33,341	$ 34,520	$ 67,861	$ 38,296	$ 9,607	$ 47,902	$ 19,959	29%
	Otter Tail Power	$ 37,238	$ 34,520	$ 71,758	$ 42,713	$ 9,607	$ 52,320	$ 19,438	27%
	Xcel Energy	$ 40,286	$ 34,520	$ 74,806	$ 47,181	$ 9,607	$ 56,788	$ 18,019	24%
St. Cloud	Minnesota Power	$ 34,784	$ 28,687	$ 63,472	$ 37,842	$ 9,052	$ 46,894	$ 16,578	26%
	Otter Tail Power	$ 38,833	$ 28,687	$ 67,520	$ 42,211	$ 9,052	$ 51,263	$ 16,257	24%
	Xcel Energy	$ 42,809	$ 28,687	$ 71,496	$ 47,241	$ 9,052	$ 56,293	$ 15,203	21%
Minneapolis	Alliant Energy	$ 40,950	$ 28,374	$ 69,323	$ 45,420	$ 8,609	$ 54,029	$ 15,295	22%
	Otter Tail Power	$ 39,702	$ 28,374	$ 68,076	$ 44,209	$ 8,609	$ 52,818	$ 15,258	22%
	Xcel Energy	$ 43,852	$ 28,374	$ 72,225	$ 48,860	$ 8,609	$ 57,469	$ 14,757	20%

Figure 71: Economics of Conventional and GHP HVAC Systems for a Small School Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 2,004,306	$ 20,306	$ 71,475	$ 2,684,254	$ 2,315,319	$ 16,104	$ 52,336	$ 2,547,384	$ 23,341	13.3	$ 136,870	5.1%
St. Cloud	$ 2,004,306	$ 20,306	$ 67,496	$ 2,647,376	$ 2,315,319	$ 16,104	$ 51,483	$ 2,538,188	$ 20,215	15.4	$ 109,188	4.1%
Minneapolis	$ 2,004,306	$ 20,306	$ 69,875	$ 2,676,470	$ 2,315,319	$ 16,104	$ 54,772	$ 2,578,424	$ 19,305	16.1	$ 98,045	3.7%

Figure 72: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small School Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 29.00	$ 0.294	$ 1.03	$ 38.84	$ 33.50	$ 0.233	$ 0.76	$ 36.86	$ 0.34	13.3	$ 1.98	5.1%
St. Cloud	$ 29.00	$ 0.294	$ 0.98	$ 38.30	$ 33.50	$ 0.233	$ 0.74	$ 36.72	$ 0.29	15.4	$ 1.58	4.1%
Minneapolis	$ 29.00	$ 0.294	$ 1.01	$ 38.73	$ 33.50	$ 0.233	$ 0.79	$ 37.31	$ 0.28	16.1	$ 1.42	3.7%

Figure 73: Annual Emissions Values for a Small School Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	1,270,094	2,299	2,240	424	0.0236	1,274,970
	GHP	1,100,587	2,639	2,274	465	0.0263	1,104,243
	Reduction	169,507	-340	-34	-40	-0.0027	170,727
	% Change	-13.3%	14.8%	1.5%	9.5%	11.6%	-13.4%
St. Cloud	Conventional	1,237,708	2,398	2,264	437	0.0244	1,242,320
	GHP	1,082,285	2,607	2,242	459	0.0260	1,085,868
	Reduction	155,424	-209	21	-22	-0.0016	156,452
	% Change	-12.6%	8.7%	-0.9%	5.0%	6.4%	-12.6%
Minneapolis	Conventional	1,254,219	2,452	2,305	446	0.0250	1,258,873
	GHP	1,123,548	2,732	2,341	480	0.0272	1,127,246
	Reduction	130,671	-280	-36	-34	-0.0023	131,627
	% Change	-10.4%	11.4%	1.5%	7.6%	9.1%	-10.5%

Figure 74: Annual Emissions Values per Square Foot for a Small School Existing Building Retrofit

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	18	0.033	0.032	0.006	0.00034	18
	GHP	16	0.038	0.033	0.007	0.00038	16
	Reduction	2	-0.005	0.000	-0.001	-0.00004	2
	% Change	-13.3%	14.8%	1.5%	9.5%	11.6%	-13.4%
St. Cloud	Conventional	18	0.035	0.033	0.006	0.00035	18
	GHP	16	0.038	0.032	0.007	0.00038	16
	Reduction	2	-0.003	0.000	0.000	-0.00002	2
	% Change	-12.6%	8.7%	-0.9%	5.0%	6.4%	-12.6%
Minneapolis	Conventional	18	0.035	0.033	0.006	0.00036	18
	GHP	16	0.040	0.034	0.007	0.00039	16
	Reduction	2	-0.004	-0.001	0.000	-0.00003	2
	% Change	-10.4%	11.4%	1.5%	7.6%	9.1%	-10.5%

Figure 75: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Small School Existing Building Retrofit

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	12	8.9	85%	76%	14.1	12.5	3.3	2.2
St. Cloud	12	9.5	85%	76%	14.1	12.5	3.3	2.2
Minneapolis	12	10.4	85%	76%	14.1	12.3	3.3	2.1

2.1.2.3 Large School, New Construction

The large school new construction building with the conventional HVAC system had electrical demand and energy consumption values ranging from 774 to 855 kW and 2,284 to 2,428 MWh, depending on location. The large school new construction building with the conventional HVAC system had natural gas requirements of 194,870 to 222,536 therms, depending on location.

The large school new construction building with the GHP HVAC system had higher electrical demand and energy consumption values, an increase of 146 to 173 kW in summer peak demand, an increase of 509 to 703 kW winter peak demand, and an increase of 485 to 621 MWh, depending on location. Based on a cursory economic analysis, electric water heating was not utilized in the GHP system.

The demand and energy consumption values are presented in Figure 76 for the large school new construction GHP retrofit.

The large school new construction building with the conventional HVAC system had total annual energy costs from $350,374 to $398,227, depending on location and utility. The large school new construction building with the GHP HVAC system had higher electrical costs but lower natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $50,503 to $86,169, or 13% to 23% of the conventional HVAC system energy costs, depending on location and utility.

The annual savings from the installation provided a simple payback of 20 to 27 years and a net decrease in life cycle costs. Economics for large school new construction installations both on an absolute basis and normalized per square foot are shown in Figure 79 and Figure 80.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 81. The installation of a GHP system in a large school new construction building reduces CO2 emissions by 3.5% to 8.2%, depending on location. All other emissions would increase due to the increased electric consumption.

Figure 76: Annual Demand and Energy Values for a Large School New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	774	2,284,108	222,536	920	2,845,109	98,487	-146	-561,001	124,049
St. Cloud	829	2,387,581	200,758	994	2,872,144	92,804	-165	-484,563	107,954
Minneapolis	855	2,428,273	194,870	1,028	3,048,907	88,257	-173	-620,634	106,613

Figure 77: Annual Demand and Energy Values per Square Foot for a Large School New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.0	5.9	0.58	2.4	7.4	0	-0.4	-1.5	0.32
St. Cloud	2.1	6.2	0.52	2.6	7.4	0	-0.4	-1.3	0.28
Minneapolis	2.2	6.3	0.50	2.7	7.9	0	-0.4	-1.6	0.28

Figure 78: Annual Energy Charges and Savings for a Large School New Construction Building

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 147,462	$ 219,554	$ 367,016	$ 183,680	$ 97,167	$ 280,848	$ 86,169	23%
	Otter Tail Power	$ 147,782	$ 219,554	$ 367,336	$ 185,247	$ 97,167	$ 282,415	$ 84,922	23%
	Xcel Energy	$ 178,673	$ 219,554	$ 398,227	$ 229,275	$ 97,167	$ 326,443	$ 71,784	18%
St. Cloud	Minnesota Power	$ 154,142	$ 198,068	$ 352,210	$ 185,426	$ 91,560	$ 276,986	$ 75,224	21%
	Otter Tail Power	$ 155,744	$ 198,068	$ 353,812	$ 193,322	$ 91,560	$ 284,882	$ 68,929	19%
	Xcel Energy	$ 188,156	$ 198,068	$ 386,224	$ 237,267	$ 91,560	$ 328,827	$ 57,397	15%
Minneapolis	Alliant Energy	$ 178,517	$ 192,259	$ 370,776	$ 228,754	$ 87,074	$ 315,829	$ 54,947	15%
	Otter Tail Power	$ 158,116	$ 192,259	$ 350,374	$ 199,280	$ 87,074	$ 286,355	$ 64,020	18%
	Xcel Energy	$ 191,306	$ 192,259	$ 383,565	$ 245,987	$ 87,074	$ 333,062	$ 50,503	13%

Figure 79: Economics of Conventional and GHP HVAC Systems for a Large School New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 9,271,872	$ 39,405	$ 377,526	$ 11,855,476	$ 11,010,348	$ 31,251	$ 296,568	$ 11,571,409	$ 89,113	19.6	$ 284,067	2.4%
St. Cloud	$ 9,271,872	$ 39,405	$ 364,082	$ 11,734,169	$ 11,010,348	$ 31,251	$ 296,898	$ 11,585,764	$ 75,338	23.3	$ 148,405	1.3%
Minneapolis	$ 9,271,872	$ 39,405	$ 368,238	$ 11,794,763	$ 11,010,348	$ 31,251	$ 311,748	$ 11,772,075	$ 64,645	27.1	$ 22,688	0.2%

Figure 80: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large School New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 24.00	$ 0.102	$ 0.98	$ 30.69	$ 28.50	$ 0.081	$ 0.77	$ 29.95	$ 0.23	19.6	$ 0.74	2.4%
St. Cloud	$ 24.00	$ 0.102	$ 0.94	$ 30.37	$ 28.50	$ 0.081	$ 0.77	$ 29.99	$ 0.20	23.3	$ 0.38	1.3%
Minneapolis	$ 24.00	$ 0.102	$ 0.95	$ 30.53	$ 28.50	$ 0.081	$ 0.81	$ 30.47	$ 0.17	27.1	$ 0.06	0.2%

Figure 81: Annual Emissions Values for a Large School New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	6,414,903	10,171	10,570	1,927	0.1062	6,440,792
	GHP	5,888,044	12,658	11,414	2,268	0.1277	5,908,884
	Reduction	526,858	-2,488	-844	-340	-0.0215	531,908
	% Change	-8.2%	24.5%	8.0%	17.7%	20.3%	-8.3%
St. Cloud	Conventional	6,330,692	10,630	10,736	1,991	0.1102	6,355,721
	GHP	5,866,125	12,778	11,457	2,284	0.1287	5,886,741
	Reduction	464,567	-2,149	-721	-293	-0.0186	468,980
	% Change	-7.3%	20.2%	6.7%	14.7%	16.9%	-7.4%
Minneapolis	Conventional	6,329,063	10,810	10,828	2,018	0.1118	6,353,924
	GHP	6,106,461	13,564	12,062	2,417	0.1364	6,127,690
	Reduction	222,602	-2,754	-1,234	-399	-0.0246	226,234
	% Change	-3.5%	25.5%	11.4%	19.8%	22.0%	-3.6%

Figure 82: Annual Emissions Values per Square Foot for a Large School New Construction Building

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	17	0.026	0.027	0.005	0.00027	17
	GHP	15	0.033	0.030	0.006	0.00033	15
	Reduction	1	-0.006	-0.002	-0.001	-0.00006	1
	% Change	-8.2%	24.5%	8.0%	17.7%	20.3%	-8.3%
St. Cloud	Conventional	16	0.028	0.028	0.005	0.00029	16
	GHP	15	0.033	0.030	0.006	0.00033	15
	Reduction	1	-0.006	-0.002	-0.001	-0.00005	1
	% Change	-7.3%	20.2%	6.7%	14.7%	16.9%	-7.4%
Minneapolis	Conventional	16	0.028	0.028	0.005	0.00029	16
	GHP	16	0.035	0.031	0.006	0.00035	16
	Reduction	1	-0.007	-0.003	-0.001	-0.00006	1
	% Change	-3.5%	25.5%	11.4%	19.8%	22.0%	-3.6%

Figure 83: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Large School New Construction Building

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	20.8	18.7	85%	75%	14.1	12.5	3.3	1.9
St. Cloud	20.8	18.9	85%	74%	14.1	12.5	3.3	1.9
Minneapolis	20.8	20.7	85%	74%	14.1	12.4	3.3	1.9

2.1.2.4 Large School, Existing Building

The large school existing building with the conventional HVAC system had electrical demand and energy consumption values ranging from 926 to 1,039 kW and 2,897 to 3,091 MWh, depending on location. The large school existing building with the conventional HVAC system had natural gas requirements of 237,229 to 281,242 therms, depending on location.

The large school existing building with the GHP HVAC system had higher electrical demand and energy consumption values, an increase of 119 to 156 kW in summer peak demand, an increase of 792 to 922 kW in winter peak demand, and an increase of 686 to 868 MWh, depending on location. Based on a cursory economic analysis, electric water heating was not utilized in the GHP system.

The demand and energy consumption values are presented in Figure 84 for the large school existing building GHP retrofit.

The large school existing building with the conventional HVAC system had total annual energy costs from $431,959 to $501,160, depending on location and utility. The large school existing building with the GHP HVAC system had higher electrical costs but lower natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $75,861 to $124,265, or 16% to 27% of the conventional HVAC system energy costs, depending on location and utility.

The annual savings from the installation provided a simple payback of 14 to 19 years and a net decrease in life cycle costs. Economics for large school existing building retrofit installations both on an absolute basis and normalized per square foot are shown in Figure 87 and Figure 88.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 89. The installation of a GHP system in a large school existing building reduces CO_2 emissions by 4.7% to 8.7%, depending on location. All other emissions would increase due to the increased electric consumption.

Figure 84: Annual Demand and Energy Values for a Large School Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	926	2,896,605	281,242	1,045	3,764,656	98,487	-119	-868,051	182,755
St. Cloud	982	3,035,195	240,152	1,117	3,721,404	92,804	-135	-686,209	147,348
Minneapolis	1,039	3,090,630	237,229	1,195	3,923,150	88,257	-156	-832,520	148,972

Figure 85: Annual Demand and Energy Values per Square Foot for a Large School Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.4	7.5	0.73	2.7	9.7	0	-0.3	-2.2	0.47
St. Cloud	2.5	7.9	0.62	2.9	9.6	0	-0.3	-1.8	0.38
Minneapolis	2.7	8.0	0.61	3.1	10.2	0	-0.4	-2.2	0.39

Figure 86: Annual Energy Charges and Savings for a Large School Existing Building Retrofit

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 187,005	$ 277,473	$ 464,478	$ 243,046	$ 97,167	$ 340,213	$ 124,265	27%
	Otter Tail Power	$ 184,520	$ 277,473	$ 461,993	$ 240,759	$ 97,167	$ 337,926	$ 124,067	27%
	Xcel Energy	$ 223,687	$ 277,473	$ 501,160	$ 297,746	$ 97,167	$ 394,913	$ 106,248	21%
St. Cloud	Minnesota Power	$ 195,952	$ 236,934	$ 432,886	$ 240,254	$ 91,560	$ 331,814	$ 101,072	23%
	Otter Tail Power	$ 195,025	$ 236,934	$ 431,959	$ 244,205	$ 91,560	$ 335,765	$ 96,194	22%
	Xcel Energy	$ 236,205	$ 236,934	$ 473,139	$ 301,136	$ 91,560	$ 392,696	$ 80,443	17%
Minneapolis	Alliant Energy	$ 224,931	$ 234,050	$ 458,981	$ 290,023	$ 87,074	$ 377,097	$ 81,884	18%
	Otter Tail Power	$ 198,586	$ 234,050	$ 432,636	$ 252,761	$ 87,074	$ 339,836	$ 92,800	21%
	Xcel Energy	$ 240,879	$ 234,050	$ 474,929	$ 311,994	$ 87,074	$ 399,068	$ 75,861	16%

Figure 87: Economics of Conventional and GHP HVAC Systems for a Large School Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 11,203,512	$ 39,405	$ 475,877	$ 14,858,555	$ 12,941,988	$ 31,251	$ 357,684	$ 14,235,588	$ 126,348	13.8	$ 622,967	4.2%
St. Cloud	$ 11,203,512	$ 39,405	$ 445,995	$ 14,575,552	$ 12,941,988	$ 31,251	$ 353,425	$ 14,194,937	$ 100,724	17.4	$ 380,615	2.6%
Minneapolis	$ 11,203,512	$ 39,405	$ 455,516	$ 14,695,019	$ 12,941,988	$ 31,251	$ 372,000	$ 14,425,898	$ 91,670	19.1	$ 269,121	1.8%

Figure 88: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large School Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 29.00	$ 0.102	$ 1.23	$ 38.46	$ 33.50	$ 0.081	$ 0.93	$ 36.85	$ 0.33	13.8	$ 1.61	4.2%
St. Cloud	$ 29.00	$ 0.102	$ 1.15	$ 37.73	$ 33.50	$ 0.081	$ 0.91	$ 36.74	$ 0.26	17.4	$ 0.99	2.6%
Minneapolis	$ 29.00	$ 0.102	$ 1.18	$ 38.04	$ 33.50	$ 0.081	$ 0.96	$ 37.34	$ 0.24	19.1	$ 0.70	1.8%

Figure 89: Annual Emissions Values for a Large School Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	8,123,704	12,898	13,395	2,443	0.1346	8,156,475
	GHP	7,416,591	16,748	14,791	2,977	0.1682	7,442,134
	Reduction	707,113	-3,850	-1,396	-533	-0.0335	714,341
	% Change	-8.7%	29.8%	10.4%	21.8%	24.9%	-8.8%
St. Cloud	Conventional	7,870,668	13,512	13,501	2,520	0.1397	7,901,524
	GHP	7,277,835	16,555	14,576	2,939	0.1661	7,302,794
	Reduction	592,833	-3,043	-1,075	-419	-0.0264	598,730
	% Change	-7.5%	22.5%	8.0%	16.6%	18.9%	-7.6%
Minneapolis	Conventional	7,928,428	13,759	13,676	2,560	0.1420	7,959,382
	GHP	7,559,700	17,452	15,272	3,091	0.1749	7,585,400
	Reduction	368,729	-3,694	-1,597	-531	-0.0328	373,981
	% Change	-4.7%	26.8%	11.7%	20.7%	23.1%	-4.7%

Figure 90: Annual Emissions Values per Square Foot for a Large School Existing Building Retrofit

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	21	0.033	0.035	0.006	0.00035	21
	GHP	19	0.043	0.038	0.008	0.00044	19
	Reduction	2	-0.010	-0.004	-0.001	-0.00009	2
	% Change	-8.7%	29.8%	10.4%	21.8%	24.9%	-8.8%
St. Cloud	Conventional	20	0.035	0.035	0.007	0.00036	20
	GHP	19	0.043	0.038	0.008	0.00043	19
	Reduction	2	-0.008	-0.003	-0.001	-0.00007	2
	% Change	-7.5%	22.5%	8.0%	16.6%	18.9%	-7.6%
Minneapolis	Conventional	21	0.036	0.035	0.007	0.00037	21
	GHP	20	0.045	0.040	0.008	0.00045	20
	Reduction	1	-0.010	-0.004	-0.001	-0.00008	1
	% Change	-4.7%	26.8%	11.7%	20.7%	23.1%	-4.7%

Figure 91: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Large School Existing Building Retrofit

	Conventional System				GHP System			
	Rated EER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	20.8	17.9	85%	75%	14.1	12.5	3.3	2.2
St. Cloud	20.8	18.5	85%	74%	14.1	12.5	3.3	2.2
Minneapolis	20.8	19.3	85%	74%	14.1	12.4	3.3	2.2

2.1.3 Residential Results

Residential buildings were analyzed using building models for small and large houses. The small and large house conventional systems are split system air conditioners with a 14 SEER with 92% rated high-efficiency furnaces for the cooling and heating, respectively. The comparisons between these and the GHP systems are detailed below.

2.1.3.1 Small House, New Construction

The small house new construction building with the conventional HVAC system had electrical demand and energy consumption values ranging from 5 to 6 kW and 11 to 12 MWh, depending on location. The small house new construction building with the conventional HVAC system had natural gas requirements of 1,083 to 1,341 therms, depending on location.

The small house new construction building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, a minimal decrease of summer demand, an increase of 4 kW in winter demand and an increase of 13 to 15 MWh, depending on location. Based on a cursory economic analysis, electric water heating was utilized in the GHP system. This allowed the gas consumption in the GHP case to be reduced to zero for all locations.

The demand and energy consumption values are presented in Figure 92 for the small house new construction GHP retrofit without the desuperheater water heating option. The demand and energy consumption values are presented in Figure 93 for the small house new construction GHP system with the desuperheater water heating option added.

The small house new construction building with the conventional HVAC system had total annual energy costs from $2,147 to $2,550, depending on location and utility. The small house new construction building with the GHP HVAC system had higher electrical costs but no natural gas costs associated. The total annual energy savings for the implementation of the GHP HVAC system ranged from $276 to $810, or 12% to 34% of the conventional HVAC system energy costs, depending on location and utility. The addition of the desuperheater water heating option increased the annual savings by an additional $50 to $83.

The annual savings from the installation provided a simple payback of 27 to 36 years and a net increase in life cycle costs. Economics for small house new construction installations both on an absolute basis and normalized per square foot are shown in Figure 98 and Figure 100.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 102 and the emissions with the addition of a desuperheater are shown in Figure 103. The installation of a GHP system in a small house new construction building increases CO2 emissions by 25.8% to 27.9%, depending on location. The addition of a desuperheater reduces CO2 emissions by 4.6% to 4.8% below this level. All other emissions would also increase due to the increased electric consumption.

Figure 92: Annual Demand and Energy Values for a Small House New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	5	11,341	1,341	5	26,649	0	0	-15,308	1,341
St. Cloud	6	12,032	1,142	6	25,705	0	0	-13,673	1,142
Minneapolis	5	12,436	1,083	5	25,292	0	0	-12,856	1,083

Figure 93: Annual Demand and Energy Values for a Small House New Construction Building with Desuperheater included in the GHP System

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	5	11,341	1,341	5	25,683	0	0	-14,342	1,341
St. Cloud	6	12,032	1,142	5	24,741	0	1	-12,709	1,142
Minneapolis	5	12,436	1,083	5	24,322	0	0	-11,886	1,083

Figure 94: Annual Demand and Energy Values per Square Foot for a Small House New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.8	6.3	0.75	2.7	14.8	0	0.1	-8.5	0.75
St. Cloud	3.3	6.7	0.63	3.2	14.3	0	0.2	-7.6	0.63
Minneapolis	2.8	6.9	0.60	2.7	14.1	0	0.1	-7.1	0.60

Figure 95: Annual Demand and Energy Values per Square Foot for a Small House New Construction Building with Desuperheater included in the GHP System

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.8	6.3	0.75	2.6	14.3	0	0.2	-8.0	0.75
St. Cloud	3.3	6.7	0.63	3.0	13.7	0	0.3	-7.1	0.63
Minneapolis	2.8	6.9	0.60	2.6	13.5	0	0.2	-6.6	0.60

Figure 96: Annual Energy Charges and Savings for a Small House New Construction Building

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 762	$ 1,612	$ 2,374	$ 1,867	$ -	$ 1,867	$ 507	21%
	Otter Tail Power	$ 787	$ 1,612	$ 2,399	$ 1,589	$ -	$ 1,589	$ 810	34%
	Xcel Energy	$ 938	$ 1,612	$ 2,550	$ 2,166	$ -	$ 2,166	$ 384	15%
St. Cloud	Minnesota Power	$ 812	$ 1,372	$ 2,184	$ 1,799	$ -	$ 1,799	$ 386	18%
	Otter Tail Power	$ 824	$ 1,372	$ 2,197	$ 1,540	$ -	$ 1,540	$ 656	30%
	Xcel Energy	$ 999	$ 1,372	$ 2,371	$ 2,092	$ -	$ 2,092	$ 280	12%
Minneapolis	Alliant Energy	$ 1,037	$ 1,302	$ 2,339	$ 1,761	$ -	$ 1,761	$ 578	25%
	Otter Tail Power	$ 846	$ 1,302	$ 2,147	$ 1,519	$ -	$ 1,519	$ 628	29%
	Xcel Energy	$ 1,034	$ 1,302	$ 2,336	$ 2,060	$ -	$ 2,060	$ 276	12%

Figure 97: Annual Energy Charges and Savings for a Small House New Construction Building with Desuperheater included in the GHP System

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 762	$ 1,612	$ 2,374	$ 1,797	$ -	$ 1,797	$ 576	24%
	Otter Tail Power	$ 787	$ 1,612	$ 2,399	$ 1,539	$ -	$ 1,539	$ 860	36%
	Xcel Energy	$ 938	$ 1,612	$ 2,550	$ 2,083	$ -	$ 2,083	$ 466	18%
St. Cloud	Minnesota Power	$ 812	$ 1,372	$ 2,184	$ 1,729	$ -	$ 1,729	$ 455	21%
	Otter Tail Power	$ 824	$ 1,372	$ 2,197	$ 1,491	$ -	$ 1,491	$ 706	32%
	Xcel Energy	$ 999	$ 1,372	$ 2,371	$ 2,010	$ -	$ 2,010	$ 361	15%
Minneapolis	Alliant Energy	$ 1,037	$ 1,302	$ 2,339	$ 1,690	$ -	$ 1,690	$ 649	28%
	Otter Tail Power	$ 846	$ 1,302	$ 2,147	$ 1,469	$ -	$ 1,469	$ 678	32%
	Xcel Energy	$ 1,034	$ 1,302	$ 2,336	$ 1,977	$ -	$ 1,977	$ 359	15%

Figure 98: Economics of Conventional and GHP HVAC Systems for a Small House New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 9,900	$ 254	$ 2,441	$ 40,113	$ 22,500	$ 292	$ 1,874	$ 39,936	$ 529	26.5	$ 177	0.4%
St. Cloud	$ 9,900	$ 254	$ 2,251	$ 38,219	$ 22,500	$ 292	$ 1,810	$ 39,167	$ 403	36.2	$ (949)	-2.5%
Minneapolis	$ 9,900	$ 254	$ 2,274	$ 38,621	$ 22,500	$ 292	$ 1,780	$ 38,802	$ 456	32.5	$ (181)	-0.5%

Figure 99: Economics of Conventional and GHP HVAC Systems for a Small House New Construction Building, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 9,900	$ 254	$ 2,441	$ 40,113	$ 23,200	$ 292	$ 1,807	$ 39,823	$ 596	24.0	$ 290	0.7%
St. Cloud	$ 9,900	$ 254	$ 2,251	$ 38,219	$ 23,200	$ 292	$ 1,743	$ 39,057	$ 470	31.0	$ (838)	-2.2%
Minneapolis	$ 9,900	$ 254	$ 2,274	$ 38,621	$ 23,200	$ 292	$ 1,712	$ 38,680	$ 524	28.0	$ (59)	-0.2%

Figure 100: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small House New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 5.50	$ 0.141	$ 1.36	$ 22.29	$ 12.50	$ 0.162	$ 1.04	$ 22.19	$ 0.29	26.5	$ 0.10	0.4%
St. Cloud	$ 5.50	$ 0.141	$ 1.25	$ 21.23	$ 12.50	$ 0.162	$ 1.01	$ 21.76	$ 0.22	36.2	$ (0.53)	-2.5%
Minneapolis	$ 5.50	$ 0.141	$ 1.26	$ 21.46	$ 12.50	$ 0.162	$ 0.99	$ 21.56	$ 0.25	32.5	$ (0.10)	-0.5%

Figure 101: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small House New Construction Building, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 5.50	$ 0.141	$ 1.36	$ 22.29	$ 12.89	$ 0.162	$ 1.00	$ 22.12	$ 0.33	24.0	$ 0.16	0.7%
St. Cloud	$ 5.50	$ 0.141	$ 1.25	$ 21.23	$ 12.89	$ 0.162	$ 0.97	$ 21.70	$ 0.26	31.0	$ (0.47)	-2.2%
Minneapolis	$ 5.50	$ 0.141	$ 1.26	$ 21.46	$ 12.89	$ 0.162	$ 0.95	$ 21.49	$ 0.29	28.0	$ (0.03)	-0.2%

Figure 102: Annual Emissions Values for a Small House New Construction Building

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	34,628	51	54	10	0.0005	34,772
	GHP	44,298	119	98	21	0.0012	44,434
	Reduction	-9,670	-68	-44	-11	-0.0006	(9,662)
	% Change	27.9%	134.6%	81.2%	110.9%	119.9%	27.8%
St. Cloud	Conventional	33,436	54	55	10	0.0006	33,570
	GHP	42,729	114	94	20	0.0011	42,860
	Reduction	-9,293	-61	-40	-10	-0.0006	(9,290)
	% Change	27.8%	113.4%	72.5%	95.7%	102.5%	27.7%
Minneapolis	Conventional	33,413	55	56	10	0.0006	33,546
	GHP	42,042	112	93	20	0.0011	42,172
	Reduction	-8,629	-57	-37	-9	-0.0005	(8,626)
	% Change	25.8%	103.1%	66.9%	87.6%	93.6%	25.7%

Figure 103: Annual Emissions Values for a Small House New Construction Building with Desuperheater included in the GHP System

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	34,628	51	54	10	0.0005	34,772
	GHP	42,692	114	94	20	0.0011	42,824
	Reduction	-8,064	-64	-40	-10	-0.0006	(8,052)
	% Change	23.3%	126.1%	74.6%	103.2%	111.9%	23.2%
St. Cloud	Conventional	33,436	54	55	10	0.0006	33,570
	GHP	41,127	110	91	19	0.0011	41,253
	Reduction	-7,691	-56	-36	-9	-0.0005	(7,683)
	% Change	23.0%	105.4%	66.1%	88.4%	94.9%	22.9%
Minneapolis	Conventional	33,413	55	56	10	0.0006	33,546
	GHP	40,430	108	89	19	0.0011	40,554
	Reduction	-7,017	-53	-34	-8	-0.0005	(7,008)
	% Change	21.0%	95.4%	60.5%	80.4%	86.2%	20.9%

Figure 104: Annual Emissions Values per Square Foot for a Small House New Construction Building

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	19	0.028	0.030	0.005	0.00030	19
	GHP	25	0.066	0.054	0.011	0.00065	25
	Reduction	-5	-0.038	-0.024	-0.006	-0.00036	-5
	% Change	27.9%	134.6%	81.2%	110.9%	119.9%	27.8%
St. Cloud	Conventional	19	0.030	0.030	0.006	0.00031	19
	GHP	24	0.064	0.052	0.011	0.00063	24
	Reduction	-5	-0.034	-0.022	-0.005	-0.00032	-5
	% Change	27.8%	113.4%	72.5%	95.7%	102.5%	27.7%
Minneapolis	Conventional	19	0.031	0.031	0.006	0.00032	19
	GHP	23	0.062	0.052	0.011	0.00062	23
	Reduction	-5	-0.032	-0.021	-0.005	-0.00030	-5
	% Change	25.8%	103.1%	66.9%	87.6%	93.6%	25.7%

Figure 105: Annual Emissions Values per Square Foot for a Small House New Construction Building with Desuperheater included in the GHP System

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	19	0.028	0.030	0.005	0.00030	19
	GHP	24	0.063	0.052	0.011	0.00063	24
	Reduction	-4	-0.035	-0.022	-0.006	-0.00033	-4
	% Change	23.3%	126.1%	74.6%	103.2%	111.9%	23.2%
St. Cloud	Conventional	19	0.030	0.030	0.006	0.00031	19
	GHP	23	0.061	0.050	0.011	0.00060	23
	Reduction	-4	-0.031	-0.020	-0.005	-0.00029	-4
	% Change	23.0%	105.4%	66.1%	88.4%	94.9%	22.9%
Minneapolis	Conventional	19	0.031	0.031	0.006	0.00032	19
	GHP	22	0.060	0.050	0.010	0.00059	23
	Reduction	-4	-0.029	-0.019	-0.005	-0.00028	-4
	% Change	21.0%	95.4%	60.5%	80.4%	86.2%	20.9%

Figure 106: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Small House New Construction Building

	Conventional System				GHP System			
	Rated SEER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	14	11.2	92%	74%	14.1	12.7	3.3	2.7
St. Cloud	14	11.1	92%	73%	14.1	12.5	3.3	2.6
Minneapolis	14	11.1	92%	73%	14.1	12.4	3.3	2.7

2.1.3.2 Small House, Existing Building

The small house existing building with the conventional HVAC system had electrical demand and energy consumption values around 6 kW and ranging from 12 to 13 MWh, depending on location. The small house existing building with the conventional HVAC system had natural gas requirements of 1,367 to 1,711 therms, depending on location.

The small house existing building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, a minimal decrease in summer demand, an increase of 5 kW in winter demand and an increase of 15 to 18 MWh, depending on location. Based on a cursory economic analysis, electric water heating was utilized in the GHP system. This allowed the gas consumption in the GHP case to be reduced to zero for all locations.

The demand and energy consumption values are presented in Figure 107 for the small house existing building GHP retrofit without the desuperheater water heating option. The demand and energy consumption values are presented in Figure 108 for the small house existing building GHP system with the desuperheater water heating option added.

The small house existing building with the conventional HVAC system had total annual energy costs from $2,530 to $3,035, depending on location and utility. The small house existing building with the GHP HVAC system had higher electrical costs, but had no natural gas costs associated because no natural gas was used in this case. The total annual energy savings for the implementation of the GHP HVAC system ranged from $453 to $1,140, or 17% to 40% of the conventional HVAC system energy costs, depending on location and utility. The addition of the desuperheater water heating option increased the annual savings by an additional $50 to $83.

The annual savings from the installation provided a simple payback of 16 to 23 years and a net decrease in life cycle costs. Economics for small house existing building retrofit installations both on an absolute basis and normalized per square foot are shown in Figure 113 and Figure 115.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 117, and the emissions with the addition of a desuperheater are shown in Figure 118. The installation of a GHP system in a small house existing building increases CO2 emissions by 21.9% to 24.3%%, depending on location. The addition of a desuperheater reduces CO2 emissions from this level by 4.0% to 4.3%. All other emissions would also increase due to the increased electric consumption.

Figure 107: Annual Demand and Energy Values for a Small House Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	6	11,802	1,711	6	29,360	0	0	-17,558	1,711
St. Cloud	6	12,713	1,397	6	28,091	0	0	-15,378	1,397
Minneapolis	6	13,223	1,367	6	27,911	0	0	-14,688	1,367

Figure 108: Annual Demand and Energy Values for a Small House Existing Building Retrofit with Desuperheater included in the GHP System

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	6	11,802	1,711	6	28,394	0	0	-16,592	1,711
St. Cloud	6	12,713	1,397	5	27,127	0	1	-14,414	1,397
Minneapolis	6	13,223	1,367	6	26,941	0	0	-13,718	1,367

Figure 109: Annual Demand and Energy Values per Square Foot for a Small House Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	3.3	6.6	0.95	3.2	16.3	0	0.2	-9.8	0.95
St. Cloud	3.3	7.1	0.78	3.2	15.6	0	0.2	-8.5	0.78
Minneapolis	3.3	7.3	0.76	3.2	15.5	0	0.2	-8.2	0.76

Figure 110: Annual Demand and Energy Values per Square Foot for a Small House Existing Building Retrofit with Desuperheater included in the GHP System

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.8	6.3	0.75	2.6	14.3	0	0.2	-8.0	0.75
St. Cloud	3.3	6.7	0.63	3.0	13.7	0	0.3	-7.1	0.63
Minneapolis	2.8	6.9	0.60	2.6	13.5	0	0.2	-6.6	0.60

Figure 111: Annual Energy Charges and Savings for a Small House Existing Building Retrofit

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 795	$ 2,056	$ 2,851	$ 2,063	$ -	$ 2,063	$ 789	28%
	Otter Tail Power	$ 812	$ 2,056	$ 2,868	$ 1,728	$ -	$ 1,728	$ 1,140	40%
	Xcel Energy	$ 978	$ 2,056	$ 3,035	$ 2,381	$ -	$ 2,381	$ 653	22%
St. Cloud	Minnesota Power	$ 861	$ 1,679	$ 2,540	$ 1,971	$ -	$ 1,971	$ 569	22%
	Otter Tail Power	$ 861	$ 1,679	$ 2,539	$ 1,663	$ -	$ 1,663	$ 877	35%
	Xcel Energy	$ 1,058	$ 1,679	$ 2,737	$ 2,285	$ -	$ 2,285	$ 453	17%
Minneapolis	Alliant Energy	$ 1,107	$ 1,643	$ 2,750	$ 1,918	$ -	$ 1,918	$ 832	30%
	Otter Tail Power	$ 887	$ 1,643	$ 2,530	$ 1,654	$ -	$ 1,654	$ 877	35%
	Xcel Energy	$ 1,103	$ 1,643	$ 2,746	$ 2,272	$ -	$ 2,272	$ 474	17%

Figure 112: Annual Energy Charges and Savings for a Small House Existing Building Retrofit with Desuperheater included in the GHP System

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 795	$ 2,056	$ 2,851	$ 1,993	$ -	$ 1,993	$ 859	30%
	Otter Tail Power	$ 812	$ 2,056	$ 2,868	$ 1,678	$ -	$ 1,678	$ 1,190	41%
	Xcel Energy	$ 978	$ 2,056	$ 3,035	$ 2,299	$ -	$ 2,299	$ 735	24%
St. Cloud	Minnesota Power	$ 861	$ 1,679	$ 2,540	$ 1,901	$ -	$ 1,901	$ 639	25%
	Otter Tail Power	$ 861	$ 1,679	$ 2,539	$ 1,613	$ -	$ 1,613	$ 926	36%
	Xcel Energy	$ 1,058	$ 1,679	$ 2,737	$ 2,203	$ -	$ 2,203	$ 535	20%
Minneapolis	Alliant Energy	$ 1,107	$ 1,643	$ 2,750	$ 1,846	$ -	$ 1,846	$ 904	33%
	Otter Tail Power	$ 887	$ 1,643	$ 2,530	$ 1,604	$ -	$ 1,604	$ 927	37%
	Xcel Energy	$ 1,103	$ 1,643	$ 2,746	$ 2,190	$ -	$ 2,190	$ 557	20%

Figure 113: Economics of Conventional and GHP HVAC Systems for a Small House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 10,440	$ 254	$ 2,918	$ 45,679	$ 23,040	$ 292	$ 2,057	$ 42,697	$ 823	16.2	$ 2,982	6.5%
St. Cloud	$ 10,440	$ 254	$ 2,605	$ 42,534	$ 23,040	$ 292	$ 1,973	$ 41,674	$ 595	23.0	$ 860	2.0%
Minneapolis	$ 10,440	$ 254	$ 2,676	$ 43,442	$ 23,040	$ 292	$ 1,948	$ 41,372	$ 690	19.9	$ 2,070	4.8%

Figure 114: Economics of Conventional and GHP HVAC Systems for a Small House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 10,440	$ 254	$ 2,918	$ 40,113	$ 23,740	$ 292	$ 1,990	$ 42,585	$ 890	15.6	$ (2,471)	-6.2%
St. Cloud	$ 10,440	$ 254	$ 2,605	$ 38,219	$ 23,740	$ 292	$ 1,906	$ 41,564	$ 662	21.3	$ (3,345)	-8.8%
Minneapolis	$ 10,440	$ 254	$ 2,676	$ 38,621	$ 23,740	$ 292	$ 1,880	$ 41,251	$ 758	18.7	$ (2,630)	-6.8%

Figure 115: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 5.80	$ 0.141	$ 1.62	$ 25.38	$ 12.80	$ 0.162	$ 1.14	$ 23.72	$ 0.46	16.2	$ 1.66	6.5%
St. Cloud	$ 5.80	$ 0.141	$ 1.45	$ 23.63	$ 12.80	$ 0.162	$ 1.10	$ 23.15	$ 0.33	23.0	$ 0.48	2.0%
Minneapolis	$ 5.80	$ 0.141	$ 1.49	$ 24.13	$ 12.80	$ 0.162	$ 1.08	$ 22.98	$ 0.38	19.9	$ 1.15	4.8%

Figure 116: Economics of Conventional and GHP HVAC Systems per Square Foot for a Small House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 5.80	$ 0.141	$ 1.62	$ 25.38	$ 13.19	$ 0.162	$ 1.11	$ 23.66	$ 0.49	15.6	$ 1.72	6.8%
St. Cloud	$ 5.80	$ 0.141	$ 1.45	$ 23.63	$ 13.19	$ 0.162	$ 1.06	$ 23.09	$ 0.37	21.3	$ 0.54	2.3%
Minneapolis	$ 5.80	$ 0.141	$ 1.49	$ 24.13	$ 13.19	$ 0.162	$ 1.04	$ 22.92	$ 0.42	18.7	$ 1.22	5.0%

Figure 117: Annual Emissions Values for a Small House Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	39,748	53	59	10	0.0006	39,917
	GHP	48,805	131	108	23	0.0013	48,955
	Reduction	-9,057	-78	-49	-12	-0.0007	(9,038)
	% Change	22.8%	148.3%	82.4%	118.2%	129.5%	22.6%
St. Cloud	Conventional	37,568	57	60	11	0.0006	37,722
	GHP	46,695	125	103	22	0.0012	46,839
	Reduction	-9,127	-68	-44	-11	-0.0006	(9,117)
	% Change	24.3%	120.6%	73.2%	99.8%	107.7%	24.2%
Minneapolis	Conventional	38,063	59	61	11	0.0006	38,218
	GHP	46,396	124	102	22	0.0012	46,539
	Reduction	-8,333	-65	-41	-10	-0.0006	(8,321)
	% Change	21.9%	110.8%	67.6%	91.9%	99.2%	21.8%

Figure 118: Annual Emissions Values for a Small House Existing Building Retrofit with Desuperheater included in the GHP System

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	39,748	53	59	10	0.0006	39,917
	GHP	47,199	126	104	22	0.0012	48,955
	Reduction	-7,451	-74	-45	-12	-0.0007	(9,038)
	% Change	18.7%	140.1%	76.4%	111.0%	121.9%	22.6%
St. Cloud	Conventional	37,568	57	60	11	0.0006	39,917
	GHP	45,093	121	100	21	0.0012	48,955
	Reduction	-7,525	-64	-40	-10	-0.0006	(9,038)
	% Change	20.0%	113.1%	67.3%	92.9%	100.6%	22.6%
Minneapolis	Conventional	38,063	59	61	11	0.0006	39,917
	GHP	44,784	120	99	21	0.0012	48,955
	Reduction	-6,721	-61	-38	-10	-0.0006	(9,038)
	% Change	17.7%	103.5%	61.8%	85.2%	92.2%	22.6%

Figure 119: Annual Emissions Values per Square Foot for a Small House Existing Building Retrofit

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	22	0.029	0.033	0.006	0.00031	22
	GHP	27	0.073	0.060	0.013	0.00072	27
	Reduction	-5	-0.043	-0.027	-0.007	-0.00040	-5
	% Change	22.8%	148.3%	82.4%	118.2%	129.5%	22.6%
St. Cloud	Conventional	21	0.031	0.033	0.006	0.00033	21
	GHP	26	0.069	0.057	0.012	0.00069	26
	Reduction	-5	-0.038	-0.024	-0.006	-0.00036	-5
	% Change	24.3%	120.6%	73.2%	99.8%	107.7%	24.2%
Minneapolis	Conventional	21	0.033	0.034	0.006	0.00034	21
	GHP	26	0.069	0.057	0.012	0.00068	26
	Reduction	-5	-0.036	-0.023	-0.006	-0.00034	-5
	% Change	21.9%	110.8%	67.6%	91.9%	99.2%	21.8%

Figure 120: Annual Emissions Values per Square Foot for a Small House Existing Building Retrofit with Desuperheater included in the GHP System

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	22	0.029	0.033	0.006	0.00031	22
	GHP	26	0.070	0.058	0.012	0.00069	27
	Reduction	-4	-0.041	-0.025	-0.006	-0.00038	-5
	% Change	18.7%	140.1%	76.4%	111.0%	121.9%	22.6%
St. Cloud	Conventional	21	0.031	0.033	0.006	0.00033	22
	GHP	25	0.067	0.055	0.012	0.00066	27
	Reduction	-4	-0.036	-0.022	-0.006	-0.00033	-5
	% Change	20.0%	113.1%	67.3%	92.9%	100.6%	22.6%
Minneapolis	Conventional	21	0.033	0.034	0.006	0.00034	22
	GHP	25	0.067	0.055	0.012	0.00066	27
	Reduction	-4	-0.034	-0.021	-0.005	-0.00032	-5
	% Change	17.7%	103.5%	61.8%	85.2%	92.2%	22.6%

Figure 121: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Small House Existing Building Retrofit

	Conventional System				GHP System			
	Rated SEER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	14	11.3	92%	77%	14.1	12.7	3.3	2.8
St. Cloud	14	11.1	92%	76%	14.1	12.5	3.3	2.7
Minneapolis	14	11.1	92%	76%	14.1	12.5	3.3	2.8

2.1.3.3 Large House, New Construction

The large house new construction building with the conventional HVAC system had electrical demand and energy consumption values ranging from 8 to 9 kW and 19 to 20 MWh, depending on location. The large house new construction building with the conventional HVAC system had natural gas requirements of 1,344 to 1,695 therms, depending on location.

The large house new construction building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, about equal summer demand, an increase of 5 kW in winter demand and an increase of 18 to 21 MWh, depending on location. Based on a cursory economic analysis, electric water heating was utilized in the GHP system. This allowed the gas consumption in the GHP case to be reduced to zero for all locations.

The demand and energy consumption values are presented in Figure 122 for the large house new construction GHP retrofit without the desuperheater water heating option. The demand and energy consumption values are presented in Figure 123 for the large house new construction GHP system with the desuperheater water heating option added.

The large house new construction building with the conventional HVAC system had total annual energy costs from $2,883 to $3,587, depending on location and utility. The large house new construction building with the GHP HVAC system had higher electrical costs but had no natural gas costs associated because no natural gas was used in this case. The total annual energy savings for the implementation of the GHP HVAC system ranged from $192 to $961, or 6% to 30% of the conventional HVAC system energy costs, depending on location and utility. The addition of the desuperheater water heating option increased the annual savings by an additional $65 to $109.

The annual savings from the installation provided a simple payback of 39 to 70 years and a net increase in life cycle costs. Economics for large house new construction installations both on an absolute basis and normalized per square foot are shown in Figure 128 and Figure 130.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 132, and the emissions with the addition of a desuperheater are shown in Figure 133. The installation of a GHP system in a large house new construction building increases CO2 emissions by 27.1% to 29.5%, depending on location. The addition of a desuperheater reduces CO2 emissions from this level by 4.2% to 4.3%. All other emissions would also increase due to the increased electric consumption.

Figure 122: Annual Demand and Energy Values for a Large House New Construction Building

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	8	18,745	1,695	8	39,656	0	0	-20,911	1,695
St. Cloud	9	19,802	1,404	9	38,498	0	0	-18,696	1,404
Minneapolis	9	20,424	1,344	9	38,041	0	0	-17,617	1,344

Figure 123: Annual Demand and Energy Values for a Large House New Construction Building with Desuperheater included in the GHP System

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	8	18,745	1,695	7	38,377	0	1	-19,632	1,695
St. Cloud	9	19,802	1,404	8	37,210	0	1	-17,408	1,404
Minneapolis	9	20,424	1,344	8	36,769	0	1	-16,345	1,344

Figure 124: Annual Demand and Energy Values per Square Foot for a Large House New Construction Building

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.7	6.2	0.57	2.6	13.2	0	0.1	-7.0	0.57
St. Cloud	3.0	6.6	0.47	2.9	12.8	0	0.1	-6.2	0.47
Minneapolis	3.0	6.8	0.45	2.9	12.7	0	0.1	-5.9	0.45

Figure 125: Annual Demand and Energy Values per Square Foot for a Large House New Construction Building with Desuperheater included in the GHP System

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	2.7	6.2	0.57	2.5	12.8	0	0.2	-6.5	0.57
St. Cloud	3.0	6.6	0.47	2.8	12.4	0	0.2	-5.8	0.47
Minneapolis	3.0	6.8	0.45	2.8	12.3	0	0.2	-5.4	0.45

Figure 126: Annual Energy Charges and Savings for a Large House New Construction Building

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 1,296	$ 2,037	$ 3,333	$ 2,806	$ -	$ 2,806	$ 528	16%
	Otter Tail Power	$ 1,182	$ 2,037	$ 3,219	$ 2,257	$ -	$ 2,257	$ 961	30%
	Xcel Energy	$ 1,550	$ 2,037	$ 3,587	$ 3,228	$ -	$ 3,228	$ 359	10%
St. Cloud	Minnesota Power	$ 1,373	$ 1,687	$ 3,060	$ 2,722	$ -	$ 2,722	$ 338	11%
	Otter Tail Power	$ 1,236	$ 1,687	$ 2,923	$ 2,198	$ -	$ 2,198	$ 726	25%
	Xcel Energy	$ 1,643	$ 1,687	$ 3,330	$ 3,138	$ -	$ 3,138	$ 192	6%
Minneapolis	Alliant Energy	$ 1,587	$ 1,615	$ 3,202	$ 2,550	$ -	$ 2,550	$ 652	20%
	Otter Tail Power	$ 1,268	$ 1,615	$ 2,883	$ 2,174	$ -	$ 2,174	$ 709	25%
	Xcel Energy	$ 1,698	$ 1,615	$ 3,313	$ 3,103	$ -	$ 3,103	$ 210	6%

Figure 127: Annual Energy Charges and Savings for a Large House New Construction Building with Desuperheater included in the GHP System

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 1,296	$ 2,037	$ 3,333	$ 2,713	$ -	$ 2,713	$ 620	19%
	Otter Tail Power	$ 1,182	$ 2,037	$ 3,219	$ 2,191	$ -	$ 2,191	$ 1,027	32%
	Xcel Energy	$ 1,550	$ 2,037	$ 3,587	$ 3,120	$ -	$ 3,120	$ 467	13%
St. Cloud	Minnesota Power	$ 1,373	$ 1,687	$ 3,060	$ 2,629	$ -	$ 2,629	$ 431	14%
	Otter Tail Power	$ 1,236	$ 1,687	$ 2,923	$ 2,132	$ -	$ 2,132	$ 792	27%
	Xcel Energy	$ 1,643	$ 1,687	$ 3,330	$ 3,028	$ -	$ 3,028	$ 302	9%
Minneapolis	Alliant Energy	$ 1,587	$ 1,615	$ 3,202	$ 2,457	$ -	$ 2,457	$ 745	23%
	Otter Tail Power	$ 1,268	$ 1,615	$ 2,883	$ 2,109	$ -	$ 2,109	$ 774	27%
	Xcel Energy	$ 1,698	$ 1,615	$ 3,313	$ 2,995	$ -	$ 2,995	$ 318	10%

Figure 128: Economics of Conventional and GHP HVAC Systems for a Large House New Construction Building, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 14,700	$ 254	$ 3,380	$ 55,346	$ 33,300	$ 292	$ 2,764	$ 57,455	$ 578	38.7	$ (2,108)	-3.8%
St. Cloud	$ 14,700	$ 254	$ 3,104	$ 52,606	$ 33,300	$ 292	$ 2,686	$ 56,512	$ 381	69.8	$ (3,906)	-7.4%
Minneapolis	$ 14,700	$ 254	$ 3,133	$ 53,070	$ 33,300	$ 292	$ 2,609	$ 55,585	$ 486	55.3	$ (2,515)	-4.7%

Figure 129: Economics of Conventional and GHP HVAC Systems for a Large House New Construction Building, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	% LCC Savings
Duluth	$ 14,700	$ 254	$ 3,380	$ 55,346	$ 34,000	$ 292	$ 2,675	$ 57,080	$ 667	32.5	$ (1,733)	-3.1%
St. Cloud	$ 14,700	$ 254	$ 3,104	$ 52,606	$ 34,000	$ 292	$ 2,596	$ 56,129	$ 470	49.3	$ (3,523)	-6.7%
Minneapolis	$ 14,700	$ 254	$ 3,133	$ 53,070	$ 34,000	$ 292	$ 2,520	$ 55,209	$ 575	40.8	$ (2,139)	-4.0%

Figure 130: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large House New Construction Building, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 4.90	$ 0.085	$ 1.13	$ 18.45	$ 11.10	$ 0.097	$ 0.92	$ 19.15	$ 0.19	38.7	$ (0.70)	-3.8%
St. Cloud	$ 4.90	$ 0.085	$ 1.03	$ 17.54	$ 11.10	$ 0.097	$ 0.90	$ 18.84	$ 0.13	69.8	$ (1.30)	-7.4%
Minneapolis	$ 4.90	$ 0.085	$ 1.04	$ 17.69	$ 11.10	$ 0.097	$ 0.87	$ 18.53	$ 0.16	55.3	$ (0.84)	-4.7%

Figure 131: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large House New Construction Building, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 4.90	$ 0.085	$ 1.13	$ 18.45	$ 11.33	$ 0.097	$ 0.89	$ 19.03	$ 0.22	32.5	$ (0.58)	-3.1%
St. Cloud	$ 4.90	$ 0.085	$ 1.03	$ 17.54	$ 11.33	$ 0.097	$ 0.87	$ 18.71	$ 0.16	49.3	$ (1.17)	-6.7%
Minneapolis	$ 4.90	$ 0.085	$ 1.04	$ 17.69	$ 11.33	$ 0.097	$ 0.84	$ 18.40	$ 0.19	40.8	$ (0.71)	-4.0%

Figure 132: Annual Emissions Values for a Large House New Construction Building

City		CO_2 (lbs)	SO_2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO_2 Eq. (lbs)
Duluth	Conventional	51,101	83	84	16	0.0009	51,305
	GHP	65,919	176	146	31	0.0017	66,122
	Reduction	-14,819	-93	-61	-15	-0.0009	(14,818)
	% Change	29.0%	111.3%	72.4%	94.6%	101.0%	28.9%
St. Cloud	Conventional	49,434	88	86	16	0.0009	49,625
	GHP	63,995	171	141	30	0.0017	64,191
	Reduction	-14,560	-83	-56	-13	-0.0008	(14,566)
	% Change	29.5%	94.2%	65.0%	82.0%	86.7%	29.4%
Minneapolis	Conventional	49,762	91	87	17	0.0009	49,952
	GHP	63,235	169	140	29	0.0017	63,429
	Reduction	-13,473	-78	-52	-13	-0.0007	(13,477)
	% Change	27.1%	86.1%	59.9%	75.1%	79.4%	27.0%

Figure 133: Annual Emissions Values for a Large House New Construction Building with Desuperheater included in the GHP System

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	51,101	83	84	16	0.0009	51,305
	GHP	63,793	171	141	30	0.0017	63,990
	Reduction	-12,693	-87	-56	-14	-0.0008	(12,685)
	% Change	24.8%	104.5%	66.9%	88.3%	94.5%	24.7%
St. Cloud	Conventional	49,434	88	86	16	0.0009	49,625
	GHP	61,854	165	137	29	0.0016	62,044
	Reduction	-12,419	-77	-51	-12	-0.0007	(12,419)
	% Change	25.1%	87.7%	59.5%	75.9%	80.5%	25.0%
Minneapolis	Conventional	49,762	91	87	17	0.0009	49,952
	GHP	61,120	164	135	28	0.0016	61,309
	Reduction	-11,358	-73	-48	-12	-0.0007	(11,356)
	% Change	22.8%	79.9%	54.5%	69.3%	73.4%	22.7%

Figure 134: Annual Emissions Values per Square Foot for a Large House New Construction Building

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	17	0.028	0.028	0.005	0.00029	17
	GHP	22	0.059	0.049	0.010	0.00058	22
	Reduction	-5	-0.031	-0.020	-0.005	-0.00029	-5
	% Change	29.0%	111.3%	72.4%	94.6%	101.0%	28.9%
St. Cloud	Conventional	16	0.029	0.029	0.005	0.00030	17
	GHP	21	0.057	0.047	0.010	0.00056	21
	Reduction	-5	-0.028	-0.019	-0.004	-0.00026	-5
	% Change	29.5%	94.2%	65.0%	82.0%	86.7%	29.4%
Minneapolis	Conventional	17	0.030	0.029	0.006	0.00031	17
	GHP	21	0.056	0.047	0.010	0.00056	21
	Reduction	-4	-0.026	-0.017	-0.004	-0.00025	-4
	% Change	27.1%	86.1%	59.9%	75.1%	79.4%	27.0%

Figure 135: Annual Emissions Values per Square Foot for a Large House New Construction Building with Desuperheater included in the GHP System

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	17	0.028	0.028	0.005	0.00029	17
	GHP	21	0.057	0.047	0.010	0.00056	21
	Reduction	-4	-0.029	-0.019	-0.005	-0.00027	-4
	% Change	24.8%	104.5%	66.9%	88.3%	94.5%	24.7%
St. Cloud	Conventional	16	0.029	0.029	0.005	0.00030	17
	GHP	21	0.055	0.046	0.010	0.00055	21
	Reduction	-4	-0.026	-0.017	-0.004	-0.00024	-4
	% Change	25.1%	87.7%	59.5%	75.9%	80.5%	25.0%
Minneapolis	Conventional	17	0.030	0.029	0.006	0.00031	17
	GHP	20	0.055	0.045	0.009	0.00054	20
	Reduction	-4	-0.024	-0.016	-0.004	-0.00023	-4
	% Change	22.8%	79.9%	54.5%	69.3%	73.4%	22.7%

Figure 136: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Large House New Construction Building

	Conventional System				GHP System			
	Rated SEER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	14	11.2	92%	74%	14.1	12.7	3.3	2.6
St. Cloud	14	11.1	92%	73%	14.1	12.5	3.3	2.6
Minneapolis	14	11.1	92%	72%	14.1	12.5	3.3	2.6

2.1.3.4 Large House, Existing Building

The large house existing building with the conventional HVAC system had electrical demand and energy consumption values around 10 kW and ranging from 19 to 21 MWh, depending on location. The large house existing building with the conventional HVAC system had natural gas requirements of 1,757 to 2,243 therms, depending on location.

The large house existing building with the GHP HVAC system had equal or lower summer electrical demand, higher winter electrical demand, and higher energy consumption values, about equal summer demand, an increase in winter demand by 6 to 7 kW and an increase of 21 to 24 MWh, depending on location. Based on a cursory economic analysis, electric water heating was utilized in the GHP system. This allowed the gas consumption in the GHP case to be reduced to zero for all locations.

The demand and energy consumption values are presented in Figure 137 for the large house existing building GHP retrofit without the desuperheater water heating option. The demand and energy consumption values are presented in Figure 138 for the large house existing building GHP system with the desuperheater water heating option added.

The large house existing building with the conventional HVAC system had total annual energy costs from $3,395 to $4,291, depending on location and utility. The large house existing building with the GHP HVAC system had higher electrical costs but had no natural gas costs associated because no natural gas was used in this case. The total annual energy savings for the implementation of the GHP HVAC system ranged from $423 to $1,453, or 11% to 37% of the conventional HVAC system energy costs, depending on location and utility. The addition of the desuperheater water heating option increased the annual savings by an additional $65 to $109.

The annual savings from the installation provided a simple payback of 20 to 34 years and a net decrease in life cycle costs. Economics for large house existing building retrofit installations both on an absolute basis and normalized per square foot are shown in Figure 143 and Figure 145.

Emissions resulting from using a conventional HVAC system and a GHP system are shown in Figure 147 and the emissions with the addition of a desuperheater are shown in Figure 148. The installation of a GHP system in a large house existing building increases CO2 emissions by 23.6% to 26.4%, depending on location. The addition of a desuperheater reduces CO2 emissions from this level by 3.6% to 3.9%. All other emissions would also increase due to the increased electric consumption.

Figure 137: Annual Demand and Energy Values for a Large House Existing Building Retrofit

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	10	19,269	2,243	10	43,439	0	0	-24,170	2,243
St. Cloud	10	20,650	1,760	10	41,838	0	0	-21,188	1,760
Minneapolis	10	21,479	1,757	10	42,136	0	0	-20,657	1,757

Figure 138: Annual Demand and Energy Values for a Large House Existing Building Retrofit with Desuperheater included in the GHP System

City	Conventional System			GHP System			Savings		
	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Duluth	10	19,269	2,243	9	42,160	0	1	-22,891	2,243
St. Cloud	10	20,650	1,760	9	40,550	0	1	-19,900	1,760
Minneapolis	10	21,479	1,757	9	40,864	0	1	-19,385	1,757

Figure 139: Annual Demand and Energy Values per Square Foot for a Large House Existing Building Retrofit

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	3.3	6.4	0.75	3.2	14.5	0	0.2	-8.1	0.75
St. Cloud	3.3	6.9	0.59	3.2	13.9	0	0.2	-7.1	0.59
Minneapolis	3.3	7.2	0.59	3.2	14.0	0	0.2	-6.9	0.59

Figure 140: Annual Demand and Energy Values per Square Foot for a Large House Existing Building Retrofit with Desuperheater included in the GHP System

	Conventional System			GHP System			Savings		
City	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf	Summer Peak W/sf	kWh/sf	Therms/sf
Duluth	3.3	6.4	0.75	3.1	14.1	0	0.2	-7.6	0.75
St. Cloud	3.3	6.9	0.59	3.1	13.5	0	0.3	-6.6	0.59
Minneapolis	3.3	7.2	0.59	3.1	13.6	0	0.3	-6.5	0.59

Figure 141: Annual Energy Charges and Savings for a Large House Existing Building Retrofit

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 1,334	$ 2,696	$ 4,030	$ 3,079	$ -	$ 3,079	$ 951	24%
	Otter Tail Power	$ 1,209	$ 2,696	$ 3,904	$ 2,452	$ -	$ 2,452	$ 1,453	37%
	Xcel Energy	$ 1,596	$ 2,696	$ 4,291	$ 3,530	$ -	$ 3,530	$ 761	18%
St. Cloud	Minnesota Power	$ 1,434	$ 2,115	$ 3,549	$ 2,963	$ -	$ 2,963	$ 586	17%
	Otter Tail Power	$ 1,280	$ 2,115	$ 3,395	$ 2,369	$ -	$ 2,369	$ 1,026	30%
	Xcel Energy	$ 1,717	$ 2,115	$ 3,832	$ 3,410	$ -	$ 3,410	$ 423	11%
Minneapolis	Alliant Energy	$ 1,675	$ 2,112	$ 3,786	$ 2,802	$ -	$ 2,802	$ 984	26%
	Otter Tail Power	$ 1,322	$ 2,112	$ 3,434	$ 2,385	$ -	$ 2,385	$ 1,049	31%
	Xcel Energy	$ 1,791	$ 2,112	$ 3,902	$ 3,437	$ -	$ 3,437	$ 465	12%

Figure 142: Annual Energy Charges and Savings for a Large House Existing Building Retrofit with Desuperheater included in the GHP System

		Conventional System			GHP System			Savings	
City	Utility	Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 1,334	$ 2,696	$ 4,030	$ 2,986	$ -	$ 2,986	$ 1,043	26%
	Otter Tail Power	$ 1,209	$ 2,696	$ 3,904	$ 2,386	$ -	$ 2,386	$ 1,518	39%
	Xcel Energy	$ 1,596	$ 2,696	$ 4,291	$ 3,422	$ -	$ 3,422	$ 870	20%
St. Cloud	Minnesota Power	$ 1,434	$ 2,115	$ 3,549	$ 2,870	$ -	$ 2,870	$ 679	19%
	Otter Tail Power	$ 1,280	$ 2,115	$ 3,395	$ 2,303	$ -	$ 2,303	$ 1,092	32%
	Xcel Energy	$ 1,717	$ 2,115	$ 3,832	$ 3,300	$ -	$ 3,300	$ 532	14%
Minneapolis	Alliant Energy	$ 1,675	$ 2,112	$ 3,786	$ 2,708	$ -	$ 2,708	$ 1,078	28%
	Otter Tail Power	$ 1,322	$ 2,112	$ 3,434	$ 2,319	$ -	$ 2,319	$ 1,115	32%
	Xcel Energy	$ 1,791	$ 2,112	$ 3,902	$ 3,329	$ -	$ 3,329	$ 573	15%

Figure 143: Economics of Conventional and GHP HVAC Systems for a Large House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 15,450	$ 254	$ 4,075	$ 63,399	$ 34,050	$ 292	$ 3,020	$ 61,308	$ 1,017	19.7	$ 2,092	3.3%
St. Cloud	$ 15,450	$ 254	$ 3,592	$ 58,534	$ 34,050	$ 292	$ 2,914	$ 60,022	$ 640	33.7	$ (1,488)	-2.5%
Minneapolis	$ 15,450	$ 254	$ 3,707	$ 59,935	$ 34,050	$ 292	$ 2,875	$ 59,545	$ 795	27.2	$ 389	0.6%

Figure 144: Economics of Conventional and GHP HVAC Systems for a Large House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

	Conventional System				GHP System				Savings			
City	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 15,450	$ 254	$ 4,075	$ 55,346	$ 34,750	$ 292	$ 2,931	$ 60,933	$ 1,106	18.5	$ (5,586)	-10.1%
St. Cloud	$ 15,450	$ 254	$ 3,592	$ 52,606	$ 34,750	$ 292	$ 2,825	$ 59,640	$ 730	29.2	$ (7,033)	-13.4%
Minneapolis	$ 15,450	$ 254	$ 3,707	$ 53,070	$ 34,750	$ 292	$ 2,786	$ 59,169	$ 884	24.2	$ (6,099)	-11.5%

Figure 145: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 5.15	$ 0.085	$ 1.36	$ 21.13	$ 11.35	$ 0.097	$ 1.01	$ 20.44	$ 0.34	19.7	$ 0.70	3.3%
St. Cloud	$ 5.15	$ 0.085	$ 1.20	$ 19.51	$ 11.35	$ 0.097	$ 0.97	$ 20.01	$ 0.21	33.7	$ (0.50)	-2.5%
Minneapolis	$ 5.15	$ 0.085	$ 1.24	$ 19.98	$ 11.35	$ 0.097	$ 0.96	$ 19.85	$ 0.26	27.2	$ 0.13	0.6%

Figure 146: Economics of Conventional and GHP HVAC Systems per Square Foot for a Large House Existing Building Retrofit, Including Simple Payback and Life Cycle Costs with Desuperheater included in the GHP System

City	Conventional System				GHP System				Savings			
	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Total Installed Cost	Annual Maintenance Costs	Annual Energy Costs	Life Cycle Costs	Annual Savings	Simple Payback (Years)	Life Cycle Savings	%LCC Savings
Duluth	$ 5.15	$ 0.085	$ 1.36	$ 21.13	$ 11.58	$ 0.097	$ 0.98	$ 20.31	$ 0.37	18.5	$ 0.82	3.9%
St. Cloud	$ 5.15	$ 0.085	$ 1.20	$ 19.51	$ 11.58	$ 0.097	$ 0.94	$ 19.88	$ 0.24	29.2	$ (0.37)	-1.9%
Minneapolis	$ 5.15	$ 0.085	$ 1.24	$ 19.98	$ 11.58	$ 0.097	$ 0.93	$ 19.72	$ 0.29	24.2	$ 0.26	1.3%

Figure 147: Annual Emissions Values for a Large House Existing Building Retrofit

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	58,419	86	91	17	0.0009	58,661
	GHP	72,208	193	160	33	0.0019	72,430
	Reduction	-13,789	-107	-68	-17	-0.0010	(13,770)
	% Change	23.6%	125.1%	74.5%	102.6%	111.2%	23.5%
St. Cloud	Conventional	55,032	92	92	17	0.0010	55,250
	GHP	69,547	186	154	32	0.0018	69,761
	Reduction	-14,515	-94	-62	-15	-0.0009	(14,511)
	% Change	26.4%	102.4%	66.9%	87.2%	93.1%	26.3%
Minneapolis	Conventional	56,375	96	95	18	0.0010	56,597
	GHP	70,042	187	155	32	0.0019	70,257
	Reduction	-13,667	-92	-60	-15	-0.0009	(13,661)
	% Change	24.2%	96.0%	62.8%	81.8%	87.3%	24.1%

Figure 148: Annual Emissions Values for a Large House Existing Building Retrofit with Desuperheater included in the GHP System

City		CO2 (lbs)	SO2 (lbs)	NOx (lbs)	PM (lbs)	Hg (lbs)	CO2 Eq. (lbs)
Duluth	Conventional	58,419	86	91	17	0.0009	58,661
	GHP	70,082	187	155	33	0.0019	72,430
	Reduction	-11,663	-102	-63	-16	-0.0010	(13,770)
	% Change	20.0%	118.5%	69.3%	96.7%	105.0%	23.5%
St. Cloud	Conventional	55,032	92	92	17	0.0010	58,661
	GHP	67,406	180	149	31	0.0018	72,430
	Reduction	-12,374	-88	-57	-14	-0.0008	(13,770)
	% Change	22.5%	96.1%	61.8%	81.4%	87.1%	23.5%
Minneapolis	Conventional	56,375	96	95	18	0.0010	58,661
	GHP	67,927	182	150	32	0.0018	72,430
	Reduction	-11,553	-86	-55	-14	-0.0008	(13,770)
	% Change	20.5%	90.0%	57.8%	76.3%	81.6%	23.5%

Figure 149: Annual Emissions Values per Square Foot for a Large House Existing Building Retrofit

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	19	0.029	0.030	0.006	0.00030	20
	GHP	24	0.064	0.053	0.011	0.00064	24
	Reduction	-5	-0.036	-0.023	-0.006	-0.00034	-5
	% Change	23.6%	125.1%	74.5%	102.6%	111.2%	23.5%
St. Cloud	Conventional	18	0.031	0.031	0.006	0.00032	18
	GHP	23	0.062	0.051	0.011	0.00061	23
	Reduction	-5	-0.031	-0.021	-0.005	-0.00030	-5
	% Change	26.4%	102.4%	66.9%	87.2%	93.1%	26.3%
Minneapolis	Conventional	19	0.032	0.032	0.006	0.00033	19
	GHP	23	0.062	0.052	0.011	0.00062	23
	Reduction	-5	-0.031	-0.020	-0.005	-0.00029	-5
	% Change	24.2%	96.0%	62.8%	81.8%	87.3%	24.1%

Figure 150: Annual Emissions Values per Square Foot for a Large House Existing Building Retrofit with Desuperheater included in the GHP System

City		CO2 (lbs/sf)	SO2 (lbs/sf)	NOx (lbs/sf)	PM (lbs/sf)	Hg x1000 (lbs/sf)	CO2 Eq. (lbs/sf)
Duluth	Conventional	19	0.029	0.030	0.006	0.00030	20
	GHP	23	0.062	0.052	0.011	0.00062	24
	Reduction	-4	-0.034	-0.021	-0.005	-0.00032	-5
	% Change	20.0%	118.5%	69.3%	96.7%	105.0%	23.5%
St. Cloud	Conventional	18	0.031	0.031	0.006	0.00032	20
	GHP	22	0.060	0.050	0.010	0.00059	24
	Reduction	-4	-0.029	-0.019	-0.005	-0.00028	-5
	% Change	22.5%	96.1%	61.8%	81.4%	87.1%	23.5%
Minneapolis	Conventional	19	0.032	0.032	0.006	0.00033	20
	GHP	23	0.061	0.050	0.011	0.00060	24
	Reduction	-4	-0.029	-0.018	-0.005	-0.00027	-5
	% Change	20.5%	90.0%	57.8%	76.3%	81.6%	23.5%

Figure 151: Annual Average Heating and Cooling System Efficiencies of Conventional and GHP Systems for a Large House Existing Building Retrofit

	Conventional System				GHP System			
	Rated SEER	Average EER	Rated Heating Efficiency	Average Heating Efficiency	Rated EER	Average EER	Rated Heating COP	Average Heating COP
Duluth	14	11.2	92%	77%	14.1	12.7	3.3	2.8
St. Cloud	14	11.1	92%	75%	14.1	12.5	3.3	2.7
Minneapolis	14	11.0	92%	76%	14.1	12.5	3.3	2.7

2.2 Comparative Analysis

Other studies have shown energy cost savings for installations of GHP systems of approximately of 20% for commercial buildings. Institutional energy savings have been shown to be on the same order, around 20%. Residential energy savings have been shown to be around as 30% in a cooling dominated climate, but around 10% or less in a heating dominated climate. This study further supports these types of results, but the effects of installing a ground source heat pump are much more complex than these simple statistics portend. This section will discuss the primary factors impacting the results, as well as noted trends with respect to energy, economics, and emissions.

2.2.1 Energy Effects Across Building Types

All conventional building models in this study show characteristics similar to available benchmark data. The installation of a GHP system increases electric consumption and decreases gas consumption in all building types examined. In Northern parts of the state, the larger heating requirements result in higher energy consumption in every case, as well as greater gas savings. In the cases of small commercial and both residential cases, the installation of a GHP system reduces gas consumption enough to justify including the replacement of gas water heating systems with electric water heating systems in the GHP installation, and possibly the installation of a desuperheater.

Electric energy consumption for cooling in small buildings was found to decrease in most cases, where the heat pumps were more efficient than the conventional system. In the larger buildings, however, electric energy consumption for cooling increased changed due to the economies of scale, which allow for the installation of highly efficient chillers, compared with the relatively less efficient modular heat pumps. This effect is most pronounced in the case of the large school, where the heat pump's EER of 14.1 is relatively inefficient when compared to the water-cooled chiller's 20.8 EER rating. In Minnesota's heating dominated climate, however, cooling energy is less important than heating energy, and GHPs consistently provide some annual energy cost savings.

Installing a GHP results in an increase of the summer peak demand in some cases and an increase in winter demand in all cases. In the cases where desuperheaters are practical for installation, the increased cooling efficiency in the summer provides more energy savings than the small extra load on the system in the winter uses, resulting in a net decrease in electric energy use. The increased winter load resulting from the installation of the desuperheater was found to occur at times that did not increase winter demand, resulting in a summer demand reduction and no effect on winter demand in every case where desuperheaters were practical for installation.

The annual average efficiencies of the heating and cooling equipment, detailed for each building in Section 2.1, do not match the rated efficiencies. This is because the heating and cooling systems rarely operate at rated conditions. The DOE2.1e modeling engine takes this into account. The efficiencies for direct expansion cooling are a function of many factors that can include outdoor temperature, humidity level, and the percent load on the compressor. Chiller efficiency is a function of the entering condenser water temperature, the leaving chilled water temperature, and the percent load on the chiller. The operating efficiency of boilers and furnaces is dependent upon the percent loading of the unit. Heat pump efficiencies are dependent upon the entering fluid temperature, entering air temperature and humidity, the percent design airflow through the heat pump, and the percent load on the compressor.

Summarized energy results for all building types are shown in Figure 152. Note that negative savings in the table indicate a net *increase* in values.

Because all cases shown in Figure 152 show a decrease in natural gas consumption and an increase in electric energy use, the viability of GHP systems is dependent on the relative price of natural gas and electricity. A sensitivity analysis with respect to this observation was conducted and the results are discussed in Section 2.2.5.2.

Figure 152: Electric Demand and Energy Savings and Gas Savings for All Building Models

		New Construction			New Construction w/ Desuperheater			Existing Building Retrofit			Existing Building Retrofit w/ Desuperheater		
	City	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms	Summer Peak kW	kWh	Therms
Small Office	Duluth	4	-28,785	7,413	5	-23,676	7,413	4	-34,181	10,723	6	-29,072	10,723
	St. Cloud	3	-25,364	6,540	5	-20,075	6,540	5	-27,412	9,098	6	-22,123	9,098
	Minneapolis	4	-24,102	6,260	5	-18,724	6,260	5	-26,317	8,881	7	-20,939	8,881
Large Office	Duluth	-18	-151,347	26,841	N/A	N/A	N/A	-24	-191,509	36,144	N/A	N/A	N/A
	St. Cloud	-17	-131,950	23,400	N/A	N/A	N/A	-24	-164,288	29,584	N/A	N/A	N/A
	Minneapolis	-16	-131,702	22,910	N/A	N/A	N/A	-21	-162,765	30,167	N/A	N/A	N/A
Small School	Duluth	3	-57,674	19,880	N/A	N/A	N/A	3	-76,747	25,252	N/A	N/A	N/A
	St. Cloud	5	-40,117	17,316	N/A	N/A	N/A	5	-47,355	19,902	N/A	N/A	N/A
	Minneapolis	6	-51,475	16,697	N/A	N/A	N/A	6	-63,173	20,033	N/A	N/A	N/A
Large School	Duluth	-146	-561,001	124,049	N/A	N/A	N/A	-119	-868,051	182,755	N/A	N/A	N/A
	St. Cloud	-165	-484,563	107,954	N/A	N/A	N/A	-135	-686,209	147,348	N/A	N/A	N/A
	Minneapolis	-173	-620,634	106,613	N/A	N/A	N/A	-156	-832,520	148,972	N/A	N/A	N/A
Small Residential	Duluth	0	-15,308	1,341	0	-14,342	1,341	0	-17,558	1,711	0	-16,592	1,711
	St. Cloud	0	-13,673	1,142	1	-12,709	1,142	0	-15,378	1,397	1	-14,414	1,397
	Minneapolis	0	-12,856	1,083	0	-11,886	1,083	0	-14,688	1,367	0	-13,718	1,367
Large Residential	Duluth	0	-20,911	1,695	1	-19,632	1,695	0	-24,170	2,243	1	-22,891	2,243
	St. Cloud	0	-18,696	1,404	1	-17,408	1,404	0	-21,188	1,760	1	-19,900	1,760
	Minneapolis	0	-17,617	1,344	1	-16,345	1,344	0	-20,657	1,757	1	-19,385	1,757

2.2.2 Economics Effects Across Building Types

In this section, system costs are compared across building types, with installed costs and O&M costs included. The comparisons in this section use life cycle cost (LCC) analysis. Other cost effects, including incentives and meter charges are discussed in Section 3.4.5, but are not included in the LCC results presented here.

2.2.2.1 Energy Costs

Conventional system annual energy costs, energy cost savings from the installation of a GHP system, and percent energy cost savings (averaged over the local major utilities) for all building types are shown in Figure 153.

Figure 153: Annual Energy Costs for Conventional HVAC Systems and Savings with Heat Pumps for All Building Models

		New Construction			New Construction w/ Desuperheater			Existing Building Retrofit			Existing Building Retrofit w/ Desuperheater		
	City	Conventional System Annual Cost	Energy Cost Savings	Percent Savings	Conventional System Annual Cost	Energy Cost Savings	Percent Savings	Conventional System Annual Cost	Energy Cost Savings	Percent Savings	Conventional System Annual Cost	Energy Cost Savings	Percent Savings
Small Office	Duluth	$ 16,882	$ 5,216	30.9%	$ 16,882	$ 5,605	33.2%	$ 22,335	$ 8,131	36.4%	$ 22,335	$ 8,520	38.1%
	St. Cloud	$ 16,374	$ 4,559	27.8%	$ 16,374	$ 4,968	30.3%	$ 21,558	$ 6,940	32.2%	$ 21,558	$ 7,350	34.1%
	Minneapolis	$ 16,113	$ 4,532	28.1%	$ 16,113	$ 4,915	30.5%	$ 21,350	$ 6,986	32.7%	$ 21,350	$ 7,369	34.5%
Large Office	Duluth	$ 74,216	$ 17,709	23.9%	N/A	N/A	N/A	$ 95,518	$ 24,440	25.6%	N/A	N/A	N/A
	St. Cloud	$ 73,498	$ 15,473	21.1%	N/A	N/A	N/A	$ 92,494	$ 19,579	21.2%	N/A	N/A	N/A
	Minneapolis	$ 75,141	$ 14,950	19.9%	N/A	N/A	N/A	$ 95,810	$ 20,203	21.1%	N/A	N/A	N/A
Small School	Duluth	$ 59,193	$ 15,237	25.7%	N/A	N/A	N/A	$ 71,475	$ 19,139	26.8%	N/A	N/A	N/A
	St. Cloud	$ 57,711	$ 13,885	24.1%	N/A	N/A	N/A	$ 67,496	$ 16,013	23.7%	N/A	N/A	N/A
	Minneapolis	$ 58,913	$ 12,454	21.1%	N/A	N/A	N/A	$ 69,875	$ 15,103	21.6%	N/A	N/A	N/A
Large School	Duluth	$ 377,526	$ 80,958	21.4%	N/A	N/A	N/A	$ 475,877	$ 118,193	24.8%	N/A	N/A	N/A
	St. Cloud	$ 364,082	$ 67,183	18.5%	N/A	N/A	N/A	$ 445,995	$ 92,569	20.8%	N/A	N/A	N/A
	Minneapolis	$ 368,238	$ 56,490	15.3%	N/A	N/A	N/A	$ 455,516	$ 83,515	18.3%	N/A	N/A	N/A
Small Residential	Duluth	$ 2,441	$ 567	23.2%	$ 2,441	$ 634	26.0%	$ 2,918	$ 861	29.5%	$ 2,918	$ 928	31.8%
	St. Cloud	$ 2,251	$ 441	19.6%	$ 2,251	$ 508	22.6%	$ 2,605	$ 633	24.3%	$ 2,605	$ 700	26.9%
	Minneapolis	$ 2,274	$ 494	21.7%	$ 2,274	$ 562	24.7%	$ 2,676	$ 728	27.2%	$ 2,676	$ 796	29.7%
Large Residential	Duluth	$ 3,380	$ 616	18.2%	$ 3,380	$ 705	20.9%	$ 4,075	$ 1,055	25.9%	$ 4,075	$ 1,144	28.1%
	St. Cloud	$ 3,104	$ 419	13.5%	$ 3,104	$ 508	16.4%	$ 3,592	$ 678	18.9%	$ 3,592	$ 768	21.4%
	Minneapolis	$ 3,133	$ 524	16.7%	$ 3,133	$ 613	19.6%	$ 3,707	$ 833	22.5%	$ 3,707	$ 922	24.9%

2.2.2.2 Life-Cycle Costs

The economics for systems over their lifetimes are best compared using a life cycle cost analysis, which normalizes all costs to present value dollars. In this analysis, future costs are normalized using a discount rate of 3% and projected energy cost indices from the DOE.

Life cycle costs were analyzed over a 15 year period, chosen based on the minimum expected useful life of equipment considered in this study. Equipment with a longer useful life was assigned a residual value at the end of the period, based on a linear depreciation. For each analysis, the annual energy costs are assumed to be equal to the average of the annual energy costs for each utility serving the climate zone under consideration. The results of the life cycle cost analysis for all building types are shown in Figure 154.

Figure 154: Life Cycle Costs, Savings, and Percent Savings for All Building Models, 15 year period

		New Construction			New Construction w/ Desuperheater			Existing Building Retrofit			Existing Building Retrofit w/ Desuperheater		
	City	Conventional LCC	LCC Savings	LCC Percent Savings	Conventional LCC	LCC Savings	LCC Percent Savings	Conventional LCC	LCC Savings	LCC Percent Savings	Conventional LCC	LCC Savings	LCC Percent Savings
Small Office	Duluth	416,536	(27,066)	-6.5%	416,536	(24,906)	-6.0%	489,519	(23,528)	-4.8%	489,519	(21,368)	-4.4%
	St. Cloud	412,039	(33,352)	-8.1%	412,039	(30,939)	-7.5%	483,170	(34,825)	-7.2%	483,170	(32,412)	-6.7%
	Minneapolis	409,424	(33,160)	-8.1%	409,424	(31,066)	-7.6%	481,083	(33,880)	-7.0%	481,083	(31,786)	-6.6%
Large Office	Duluth	2,382,494	81,650	3.4%	N/A	N/A	N/A	2,695,863	(4,813)	-0.2%	N/A	N/A	N/A
	St. Cloud	2,380,375	61,142	2.6%	N/A	N/A	N/A	2,671,806	(51,075)	-1.9%	N/A	N/A	N/A
	Minneapolis	2,401,119	55,772	2.3%	N/A	N/A	N/A	2,710,646	(44,660)	-1.6%	N/A	N/A	N/A
Small School	Duluth	2,201,302	99,931	4.5%	N/A	N/A	N/A	2,684,254	136,870	5.1%	N/A	N/A	N/A
	St. Cloud	2,189,247	88,416	4.0%	N/A	N/A	N/A	2,647,376	109,188	4.1%	N/A	N/A	N/A
	Minneapolis	2,205,607	72,400	3.3%	N/A	N/A	N/A	2,676,470	98,045	3.7%	N/A	N/A	N/A
Large School	Duluth	11,855,476	284,067	2.4%	N/A	N/A	N/A	14,858,555	622,967	4.2%	N/A	N/A	N/A
	St. Cloud	11,734,169	148,405	1.3%	N/A	N/A	N/A	14,575,552	380,615	2.6%	N/A	N/A	N/A
	Minneapolis	11,794,763	22,688	0.2%	N/A	N/A	N/A	14,695,019	269,121	1.8%	N/A	N/A	N/A
Small Residential	Duluth	40,113	177	0.4%	40,113	290	0.7%	45,679	2,982	6.5%	45,679	3,095	6.8%
	St. Cloud	38,219	(949)	-2.5%	38,219	(838)	-2.2%	42,534	860	2.0%	42,534	971	2.3%
	Minneapolis	38,621	(181)	-0.5%	38,621	(59)	-0.2%	43,442	2,070	4.8%	43,442	2,192	5.0%
Large Residential	Duluth	55,346	(2,108)	-3.8%	55,346	(1,733)	-3.1%	63,399	2,092	3.3%	63,399	2,467	3.9%
	St. Cloud	52,606	(3,906)	-7.4%	52,606	(3,523)	-6.7%	58,534	(1,488)	-2.5%	58,534	(1,106)	-1.9%
	Minneapolis	53,070	(2,515)	-4.7%	53,070	(2,139)	-4.0%	59,935	389	0.6%	59,935	765	1.3%

2.2.2.3 Characteristics of GHP Systems Found to Be Cost Effective

The most important factor for considering cost-effectiveness of a GHP system, from the results shown above, is the availability of a low-cost alternative. Installations where a relatively low cost conventional system is not available prove to be more cost effective than installations where a relatively low cost conventional system is available.

Desuperheaters provide an added benefit for both annual energy costs and life-cycle costs for those systems where they make sense for installation.

2.2.2.4 Characteristics of GHP Systems Found Not to Be Cost Effective

No characteristics of GHP systems shown above were determined not to be cost effective. As the figure shows, conventional HVAC systems may be more cost effective, depending upon the application. Poor site selection, which would cause excessive installation costs, is an important characteristic of a GHP system that could cause it not to be cost effective.

2.2.3 Emissions Effects Across Building Types

Each system under consideration results in emissions that occur directly, as from a natural gas furnace, or indirectly, through the emissions of a power plant generating electricity using fossil fuels. The emissions considered in this study can be categorized into two classifications: greenhouse gas emissions, which include the effects of nitrous oxide (N2O) and carbon dioxide (CO2), and other emissions, which include mercury (Hg), particulate matter (PM), and sulfur dioxide (SO2).

In the results shown for the greenhouse gas emissions, global warming potential values were determined for each scenario. Global warming potential is a scale that uses CO2 as a reference and compares the global warming potential of a substance to the same mass of CO2 within a given timescale. The magnitude of the effect that each substance is attributed is a function of both the efficiency of the molecule as a greenhouse gas and the expected atmospheric lifetime. For the purposes of this study, only the effects of CO2 and N2O emissions were considered. N2O is determined to have the equivalent global warming potential of 296 times that of CO2. Greenhouse gas emissions and non-greenhouse gas emissions are shown in Figure 155 and Figure 156, respectively. For purposes of these figures, note that a negative reduction is a net *increase* in emissions.

The installation of a GHP system in all building types results in increases in non-greenhouse gas emissions. The installation of a GHP system in a small office and small school results in a net reduction of greenhouse gas emissions, and installations of GHP systems in all other buildings analyzed result in increases in greenhouse gas emissions.

Emissions from the various building types showed consistent patterns within each type. Because residential systems rely heavily on natural gas for space heating (as compared to commercial and institutional buildings that have higher internal gains) in conventional systems, the simulations showed an increase for both GHG and non-GHG emissions when GHP systems are installed. In offices and schools, higher internal gains led to lower natural gas heating requirements. In these cases, smaller buildings with less efficient conventional systems showed a significant decrease in greenhouse gas emissions when a GHP system was installed, while large, efficient conventional systems showed a more modest reduction in greenhouse gas emissions when a GHP system was installed.

Natural gas is primarily methane, and produces less non-greenhouse gas, environmental pollutant emissions when combusted at conventional equipment efficiencies than any alternative electric-based heating system. Due to this difference, the analysis of this report shows that *all* GHP systems result in increased non-greenhouse gas emissions.

Figure 155: Greenhouse Gas Emissions Reductions with GHP Systems, compared to Conventional Systems (lb/year) for All Building Models

	City	New Construction			New Construction w/ Desuperheater			Existing Building Retrofit			Existing Building Retrofit w/ Desuperheater		
		CO2 lb/year	NOx lb/year	CO2 Eq. Lb/year	CO2 lb/year	NOx lb/year	CO2 Eq. Lb/year	CO2 lb/year	NOx lb/year	CO2 Eq. Lb/year	CO2 lb/year	NOx lb/year	CO2 Eq. Lb/year
Small Office	Duluth	39,363	(37)	39,689	47,856	(14)	48,208	69,334	(27)	69,844	77,827	(4)	78,363
	St. Cloud	34,779	(33)	35,067	43,571	(10)	43,886	61,469	(17)	61,909	70,261	6	70,728
	Minneapolis	33,583	(31)	33,859	42,522	(7)	42,826	60,736	(15)	61,168	69,676	9	70,136
Large Office	Duluth	64,195	(293)	65,135	N/A	N/A	N/A	106,882	(349)	108,210	N/A	N/A	N/A
	St. Cloud	55,956	(255)	56,775	N/A	N/A	N/A	74,954	(313)	76,002	N/A	N/A	N/A
	Minneapolis	50,604	(259)	51,393	N/A	N/A	N/A	84,345	(302)	85,438	N/A	N/A	N/A
Small School	Duluth	138,012	(17)	138,986	N/A	N/A	N/A	169,507	(34)	170,727	N/A	N/A	N/A
	St. Cloud	137,032	22	137,932	N/A	N/A	N/A	155,424	21	156,452	N/A	N/A	N/A
	Minneapolis	110,869	(25)	111,672	N/A	N/A	N/A	130,671	(36)	131,627	N/A	N/A	N/A
Large School	Duluth	526,858	(844)	531,908	N/A	N/A	N/A	707,113	(1,396)	714,341	N/A	N/A	N/A
	St. Cloud	464,567	(721)	468,980	N/A	N/A	N/A	592,833	(1,075)	598,730	N/A	N/A	N/A
	Minneapolis	222,602	(1,234)	226,234	N/A	N/A	N/A	368,729	(1,597)	373,981	N/A	N/A	N/A
Small Residential	Duluth	(9,670)	(44)	(9,662)	(8,064)	(40)	(8,052)	(9,057)	(49)	(9,662)	(7,451)	(45)	(8,052)
	St. Cloud	(9,293)	(40)	(9,290)	(7,691)	(36)	(7,683)	(9,127)	(44)	(9,290)	(7,525)	(40)	(7,683)
	Minneapolis	(8,629)	(37)	(8,626)	(7,017)	(34)	(7,008)	(8,333)	(41)	(8,626)	(6,721)	(38)	(7,008)
Large Residential	Duluth	(14,819)	(61)	(14,818)	(12,693)	(56)	(12,685)	(13,789)	(68)	(14,818)	(11,663)	(63)	(12,685)
	St. Cloud	(14,560)	(56)	(14,566)	(12,419)	(51)	(12,419)	(14,515)	(62)	(14,566)	(12,374)	(57)	(12,419)
	Minneapolis	(13,473)	(52)	(13,477)	(11,358)	(48)	(11,356)	(13,667)	(60)	(13,477)	(11,553)	(55)	(11,356)

Figure 156: Non-Greenhouse Gas Emissions Reductions with GHP Systems, compared to Conventional Systems (lb/year) for All Building Models

		New Construction			New Construction w/ Desuperheater			Existing Building Retrofit			Existing Building Retrofit w/ Desuperheater		
	City	SO2 lb/year	PM lb/year	Hg lb/year	SO2 lb/year	PM lb/year	Hg lb/year	SO2 lb/year	PM lb/year	Hg lb/year	SO2 lb/year	PM lb/year	Hg lb/year
Small Office	Duluth	(127.6)	(16.7)	(0.0011)	(104.9)	(12.7)	(0.0009)	(151.4)	(18.4)	(0.0012)	(128.7)	(14.4)	(0.0010)
	St. Cloud	(112.4)	(14.7)	(0.0009)	(88.9)	(10.6)	(0.0007)	(121.4)	(14.4)	(0.0010)	(97.8)	(10.3)	(0.0007)
	Minneapolis	(106.8)	(13.9)	(0.0009)	(82.9)	(9.8)	(0.0007)	(116.5)	(13.7)	(0.0009)	(92.6)	(9.5)	(0.0007)
Large Office	Duluth	(671.5)	(96.7)	(0.0060)	N/A	N/A	N/A	(849.5)	(120.8)	(0.0075)	N/A	N/A	N/A
	St. Cloud	(585.4)	(84.3)	(0.0052)	N/A	N/A	N/A	(728.9)	(104.7)	(0.0065)	N/A	N/A	N/A
	Minneapolis	(584.4)	(84.5)	(0.0052)	N/A	N/A	N/A	(722.1)	(103.0)	(0.0064)	N/A	N/A	N/A
Small School	Duluth	(255.3)	(29.7)	(0.0020)	N/A	N/A	N/A	(339.8)	(40.4)	(0.0027)	N/A	N/A	N/A
	St. Cloud	(177.4)	(18.0)	(0.0013)	N/A	N/A	N/A	(209.4)	(21.7)	(0.0016)	N/A	N/A	N/A
	Minneapolis	(227.9)	(27.3)	(0.0018)	N/A	N/A	N/A	(279.8)	(33.8)	(0.0023)	N/A	N/A	N/A
Large School	Duluth	(2,487.6)	(340.2)	(0.0215)	N/A	N/A	N/A	(3,849.6)	(533.3)	(0.0335)	N/A	N/A	N/A
	St. Cloud	(2,148.6)	(293.3)	(0.0186)	N/A	N/A	N/A	(3,043.0)	(419.4)	(0.0264)	N/A	N/A	N/A
	Minneapolis	(2,753.8)	(399.2)	(0.0246)	N/A	N/A	N/A	(3,693.6)	(531.0)	(0.0328)	N/A	N/A	N/A
Small Residential	Duluth	(68.0)	(10.8)	(0.0006)	(63.7)	(10.1)	(0.0006)	(78.0)	(12.3)	(0.0007)	(73.7)	(11.5)	(0.0007)
	St. Cloud	(60.7)	(9.7)	(0.0006)	(56.5)	(9.0)	(0.0005)	(68.3)	(10.8)	(0.0006)	(64.0)	(10.1)	(0.0006)
	Minneapolis	(57.1)	(9.1)	(0.0005)	(52.8)	(8.4)	(0.0005)	(65.2)	(10.3)	(0.0006)	(60.9)	(9.6)	(0.0006)
Large Residential	Duluth	(92.9)	(14.9)	(0.0009)	(87.2)	(13.9)	(0.0008)	(107.4)	(17.0)	(0.0010)	(101.7)	(16.0)	(0.0010)
	St. Cloud	(83.1)	(13.4)	(0.0008)	(77.3)	(12.4)	(0.0007)	(94.1)	(15.0)	(0.0009)	(88.4)	(14.0)	(0.0008)
	Minneapolis	(78.3)	(12.6)	(0.0007)	(72.6)	(11.6)	(0.0007)	(91.8)	(14.6)	(0.0009)	(86.1)	(13.6)	(0.0008)

2.2.4 Key Characteristics of GHP Installations

Many characteristics impact the effectiveness of heat pump systems. In the context of this study, some of these characteristics were found to be more important than others, affecting energy consumption, system economics, emissions, or any combination of these. The key characteristics include

- system costs,
- utility energy charges,
- conventional system types, and
- climate factors.

Specific implications of each of these effects are discussed below. Other characteristics were investigated and found to be less significant:

- Heat pump performance at a given time varies with water temperature, but the annual energy consumption was not found to vary significantly as a result of the annual changes in ground temperature (and resulting water loop temperature).
- The number and depth of wells is also of minimal importance to the system energy consumption. Wells are most cost effective when drilled as deep as reasonably possible before significant impediments (like bedrock) are encountered, within standard pipe lengths.

The considerations listed above are both important for specific site design, and require well-trained professionals for proper design of individual systems.

2.2.5 Sensitivity Analyses

A few factors were identified that may have a significant impact on the results of this report. Sensitivity analyses were conducted to determine the impact of the inclusion of energy recovery ventilators in the GHP systems, the heating fuel type used in a building, and the relative prices of gas and electricity. Discussions of these three investigations are included below.

2.2.5.1 Energy Savings From GHP Systems vs. Savings From Energy Recovery Ventilators

Energy recovery ventilators (ERVs) are included in each of the commercial and institutional buildings' GHP systems. ERVs reduce ventilation energy requirements, so a sensitivity analysis was conducted to assess the savings associated with the heat pump as compared to the savings associated with the ERV, which could also be installed on the conventional system. The ERV was found to provide only minimal savings as compared to the GHP system. For example, as shown in Figure 157 and Figure 158, in the small office new construction building, the GHP system without an ERV saves from 22% to 30% on the annual energy bills, while the GHP system with an ERV saves 23% to 32% on the annual energy bills. The ERVs are included in the GHP systems to help reduce peak loads and required well field size, not for a significant energy savings.

Figure 157: Annual Energy Charges and Savings for a Small Office New Construction Building with ERV Installed

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 8,538	$ 7,314	$ 15,852	$ 10,472	$ -	$ 10,472	$ 5,380	34%
	Otter Tail Power	$ 10,265	$ 7,314	$ 17,578	$ 12,318	$ -	$ 12,318	$ 5,260	30%
	Xcel Energy	$ 9,902	$ 7,314	$ 17,215	$ 12,207	$ -	$ 12,207	$ 5,008	29%
St. Cloud	Minnesota Power	$ 8,866	$ 6,452	$ 15,319	$ 10,638	$ -	$ 10,638	$ 4,681	31%
	Otter Tail Power	$ 10,624	$ 6,452	$ 17,076	$ 12,433	$ -	$ 12,433	$ 4,643	27%
	Xcel Energy	$ 10,274	$ 6,452	$ 16,726	$ 12,374	$ -	$ 12,374	$ 4,352	26%
Minneapolis	Alliant Energy	$ 8,673	$ 6,176	$ 14,849	$ 9,985	$ -	$ 9,985	$ 4,863	33%
	Otter Tail Power	$ 10,764	$ 6,176	$ 16,940	$ 12,483	$ -	$ 12,483	$ 4,457	26%
	Xcel Energy	$ 10,373	$ 6,176	$ 16,550	$ 12,274	$ -	$ 12,274	$ 4,275	26%

Figure 158: Annual Energy Charges and Savings for a Small Office New Construction Building with No ERV Installed

City	Utility	Conventional System			GHP System			Savings	
		Electric	Gas	Total	Electric	Gas	Total	Total	(%)
Duluth	Minnesota Power	$ 8,538	$ 7,314	$ 15,852	$ 10,717	$ -	$ 10,717	$ 5,135	32%
	Otter Tail Power	$ 10,265	$ 7,314	$ 17,578	$ 12,617	$ -	$ 12,617	$ 4,962	28%
	Xcel Energy	$ 9,902	$ 7,314	$ 17,215	$ 12,465	$ -	$ 12,465	$ 4,750	28%
St. Cloud	Minnesota Power	$ 8,866	$ 6,452	$ 15,319	$ 10,848	$ -	$ 10,848	$ 4,470	29%
	Otter Tail Power	$ 10,624	$ 6,452	$ 17,076	$ 12,698	$ -	$ 12,698	$ 4,378	26%
	Xcel Energy	$ 10,274	$ 6,452	$ 16,726	$ 12,593	$ -	$ 12,593	$ 4,134	25%
Minneapolis	Alliant Energy	$ 8,673	$ 6,176	$ 14,849	$ 10,064	$ -	$ 10,064	$ 4,784	32%
	Otter Tail Power	$ 10,764	$ 6,176	$ 16,940	$ 12,594	$ -	$ 12,594	$ 4,346	26%
	Xcel Energy	$ 10,373	$ 6,176	$ 16,550	$ 12,336	$ -	$ 12,336	$ 4,213	25%

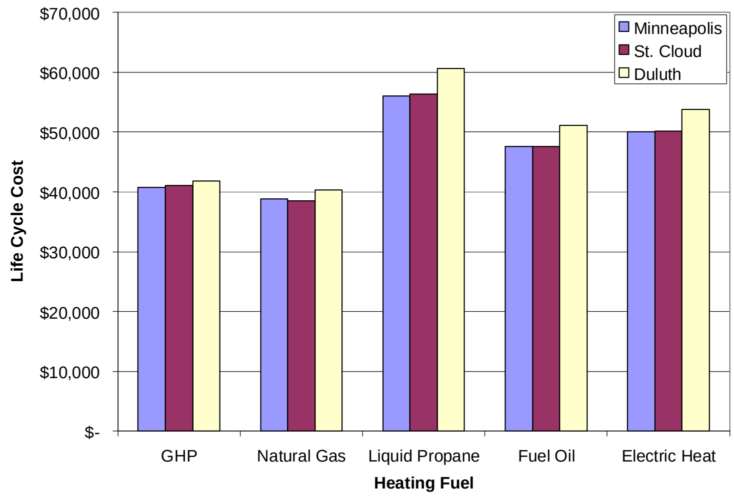
2.2.5.2 LCC and Emissions Analysis Due to Fuel Type Distribution

A variety of heating fuels are used in Minnesota (37). The widest variance is in the residential sector. Economic sensitivity analysis was conducted for electric heat, natural gas, fuel oil, and liquid propane (LP) in the residential sector. Because there is much less diversity in the commercial and institutional sectors' conventional heating systems, this sensitivity analysis focuses on the residential sector.

Natural gas prices were supplied from an Energy Information Administration (EIA) study (35). The average 2007 retail natural gas price in Minnesota was $12.018 / MCF in the residential market and $9.866 / MCF in the commercial market. Number two fuel oil and LPG costs were estimated from the Minnesota SHOPP (State Heating Oil and Propane Program) report as $3.10 per gallon and $1.98 per gallon, respectively, in the last quarter of 2007. These fuel costs include both the fuel costs and distribution charges.

The small residential new construction building was selected for the sensitivity analysis. The energy required for heating was adjusted by the respective fuel prices and life cycle costs were calculated with the new annual costs. The results of this life cycle cost comparison are shown in Figure 159.

Figure 159: Total Life Cycle Cost for Small Residential New Construction Building with Respect to Heating Fuel

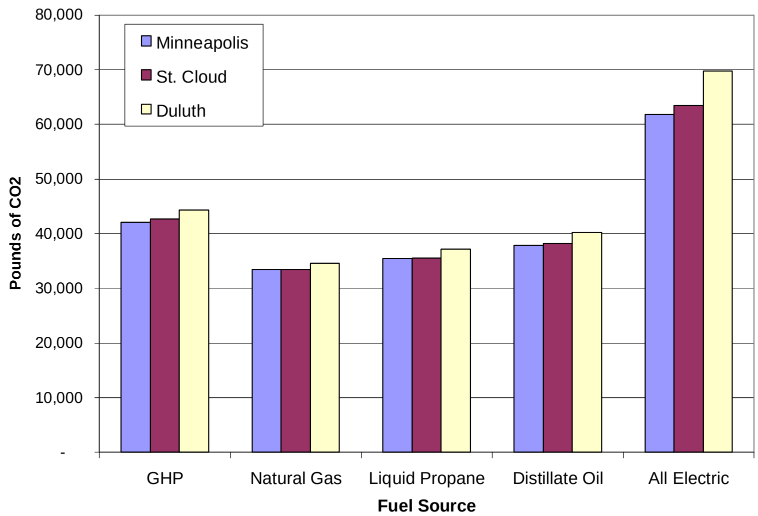


Emissions are also affected by the fuel type selected. The specific emissions factors shown in Figure 160 were assumed to be representative of emissions associated with non-electric space and water heating fuel use. The values in Figure 160 were derived from EPA AP-42 Chapter 1 emissions factors (36). These factors were applied to the energy consumption for the small residential new construction building and the resulting CO2 emissions are shown in Figure 161.

Figure 160: Non-electric Specific Emissions Factors, Including Other Heating Fuels

	CO2	SO2	NOx	N2O	PM
Units	lbs/MMBTU	lbs/MMBTU	lbs/MMBTU	lbs/MMBTU	lbs/MMBTU
Residential Natural Gas Furnace	117.6	5.882E-04	9.216E-02	2.157E-03	7.451E-03
Commercial Small Natural Gas Boiler	117.6	5.882E-04	9.804E-02	2.157E-03	7.451E-03
LP	136.6	2.186E-04	1.530E-01	1.420E-03	4.372E-03
Residential Fuel Oil Furnace	159.3	5.071E-01	1.286E-01	1.656E-03	2.857E-03
Commercial Small Distillate Oil Boiler	159.3	5.071E-01	1.429E-01	1.656E-03	1.429E-02
Commercial Small #6 Fuel Oil Boiler	178.6	1.963E+00	3.929E-01	1.856E-03	7.143E-02

Figure 161: Annual CO2 Emissions for Small Residential New Construction Building with Respect to Heating Fuel



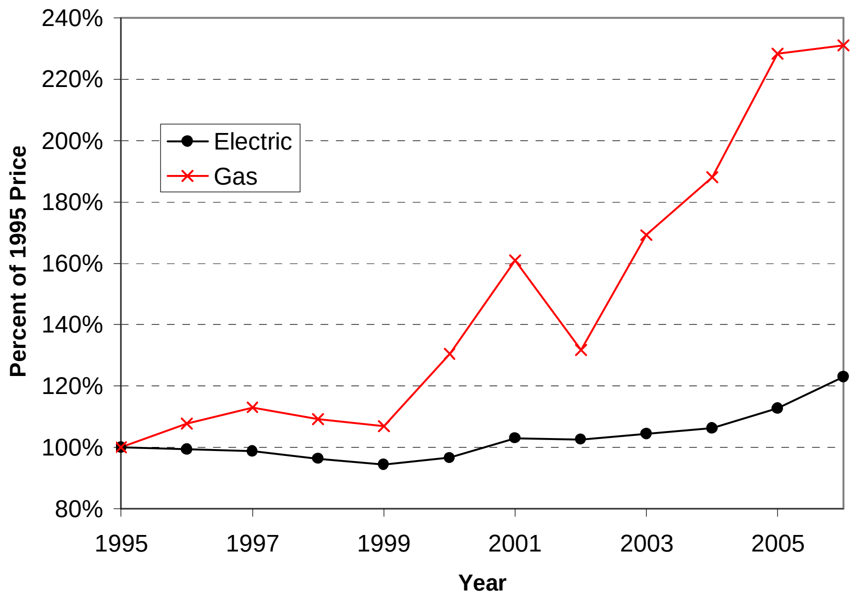
2.2.5.3 LCC Analysis Due to Variations in the Relative Prices of Gas and Electricity

The life cycle cost analysis from Section 2.2.5.2 was not favorable for residences using natural gas as the primary heat source. A similar situation exists for small office buildings. The small office building has the greatest difference in life cycle costs. This situation will change as the price of gas changes. The relative price of gas with respect to the price of electricity is investigated here.

Recent changes in natural gas and electricity prices have shown faster growth in natural gas prices than in electricity prices. This trend is shown in Figure 162, normalized to 1995 costs (38). If this trend continues, the economic viability of GHP systems may change. A sensitivity analysis indicates that if the cost of natural gas were only 40% greater with respect to electric prices, GHP systems would have a beneficial 15-year life cycle cost for a Minneapolis small office new construction building as compared with a conventional system.

Because the small office new construction building showed the worst life cycle cost comparison, other buildings would result in a beneficial life-cycle cost at a lower relative natural gas cost. Although current price predictions do not anticipate the cost of natural gas rising this significantly with respect to electric energy prices, natural gas prices have risen at a rate faster than electricity in recent history, so it is a possibility worth monitoring.

Figure 162: Natural Gas and Electrical Energy Costs with Respect to 1995 Prices



3 Current Status and Market Potential of GHP Systems

3.1 Manufacturers and Installers of GHP Systems

There are currently twenty-nine installers and one manufacturer for GHP systems listed in Minnesota. A complete list of installers is included in Appendix A.

3.2 Existing Installations of GHP Systems

According to the US Census Bureau, there were 1,569,515 residences and 149,504 commercial and institutional buildings in Minnesota in 2004 (The census bureau does not differentiate between commercial and institutional buildings in their major classifications). Of the latter, about 25,000 were office buildings and 7,514 were educational facilities. A portion of these are in urban areas, such as the twin cities metro area, and are not expected to have sufficient land available for GHP installation, as detailed in Figure 164. Nearly 26,000 new houses and 260 new offices and educational facilities are built each year.

Assuming an 18 year life on typical existing HVAC systems (based on expected equipment life in Section 1.3.1.5) and adding the new construction for these buildings types provides a market of nearly 80,000 buildings annually. In 2005, there were 1,011 reported GHP shipments to Minnesota (39). These figures show a current annual penetration rate for GHP systems of about one and one quarter percent (1.27%).

3.3 Available Incentives for the Installation of GHP Systems

As a part of existing Conservation Improvement Plan programs, the Investor Owned Utilities (IOUs) in the state have various levels of incentives encouraging users to install GHP systems. Figure 163 shows the current incentive levels offered by the IOUs in Minnesota. This information was not readily available for many of the smaller utilities and co-ops, and therefore those incentives are not included in this study.

Figure 163: Utility Incentives for GHP Installation in Minnesota

	Base Cooling Incentive	Cooling Efficiency Incentive	Base Heating Incentive	Heating Efficiency Incentive	Desuperheater Incentive
	($/ton)	$/(EER-EER$_{min}$)	($/1000 BTU)	($)	($)
Alliant Energy					
Open Loop	$300	$150		$150	$200
Closed Loop	$300	$150		$150	$200
Minnesota Power					
Open Loop	$200				
Closed Loop	$150				
Ottertail Power					
Open Loop			$18		
Closed Loop			$18		
Xcel Energy-Residential					
Open Loop					
Closed Loop	$150				
Xcel Energy-Commercial					
Open Loop	Custom - $200/kW				
Closed Loop	Custom - $200/kW				

In the table above the Alliant Energy cooling efficiency rebate uses a minimum EER value of 14.1 BTU/W-h.

3.4 Economic Development Potential

If GHP systems were installed on a large scale, the installations would have a positive economic impact on the state of Minnesota.

The life-cycle cost (LCC) analysis from Section 2.2.2.2 demonstrates that installing GHP systems would have a positive value proposition for new large office buildings, some residential retrofits, and new and retrofit schools. A positive value proposition is defined as a lower LCC than the conventional HVAC alternative.

3.4.1 Residential Potential

The residential LCC sensitivity analysis discussed earlier in Section 2.2.5.2 found GHP systems to be more cost effective that conventional systems when compared with homes using fuel oil and LP for heating. Therefore, the estimate of number of instances when GHP systems would be cost effective in residential buildings is based on the number of homes using LP or fuel oil as their primary heat source. Not all of the houses using LP or fuel oil are expected to switch to GHP systems, but these numbers are used to represent the most likely candidates to make a change, based on the LCC analysis.

Data from the Energy Information Administration (EIA) indicate that 16% of Minnesota residences use LP or fuel oil (37). This represents about 12,500 retrofit and new construction opportunities annually statewide. An aggressive campaign with modest incentives would be able to capture 40% of this potential (40), subject to owner preference and site suitability, resulting in nearly 5,000 residential installations annually. Incentives may or may not be available through the utilities providing electricity due to the increase in consumption and fuel switching issues.

3.4.2 Commercial and Institutional Potential

The commercial building analysis is favorable for schools and large office buildings. Data are not available indicating the separation between small and large office buildings. Therefore, the total population of office buildings was used in this analysis. This was deemed acceptable since 10% of small office buildings have propane or fuel oil as their primary heat source (37) and assumed penetration rates for office buildings are consistent with these data. Similar to the case with the residential installations, not all installations will replace LP and fuel oil, but these buildings provide the greatest financial potential. As a result, the total potential for office building installations is over 1,400 buildings annually. Research indicates penetration rates of 3% and 10% are achievable for retrofit and new construction respectively (40).

Thirty-nine schools were built in Minnesota from 1999 through 2004. In addition, there are 7,514 existing educational facilities in Minnesota. Extending this data provides an annual potential of 374 educational buildings. Penetration rates of 3% and 20% were used in developing potential for retrofit and new construction, respectively.

Details of the residential and commercial/institutional potential markets are shown in Figure 164.

Figure 164: Market Potential for GHP Systems in Minnesota

	MN Total Buildings	Non-Twin Cities Buildings	Buildings with LP & Oil	Annual Market	Projected Penetration Rate (%)	Projected Annual GHP Projects
Retrofit						
Residences	1,569,515	1,381,173	16%	12,277	40%	4,911
Offices	25,000	22,000	10%	1,222	3%	37
Schools	7,514	6,612	10%	367	3%	11
Subtotal		1,409,786		13,867		4,959
New Construction						
Residences	25,897	22,789	16%	203	40%	81
Offices	251	221	10%	221	10%	22
Schools	8	7	10%	7	20%	1
Subtotal		23,017				105
Total		1,432,803				5,063

3.4.3 Economic Impact

The installation of GHP systems at the levels described here would require an investment of over $108 Million in capital cost increases – equipment and installation costs above the costs of conventional systems. This investment would result in a loss of jobs in some sectors, such as LP and fuel oil installation, but a net increase in HVAC installation and well drilling jobs, as described below.

The net result of this analysis is an increase in GHP installations to over 5,000 annually, shown in Figure 164, for the selected residential, commercial, and institutional buildings. These conversions will result in a net reduction in energy imports to Minnesota, valued at $5.4 million, per the values listed earlier in this study. Fuel consumption will be reduced by 11.3 million therms per year (natural gas, equivalent LP and fuel oil). Electricity consumption will increase by 106,000 MWh per year and summer peak generation requirements will increase by over 400 kW each year.

Installing these GHP systems will add a net $88.3 million annually to Minnesota's economy in the net increase in installation costs. This does not include the cost of the heat pump itself. Minnesota has one native GHP manufacturer, and the total shipments of the one manufacturer are not expected to significantly affect the gross economic development potential result due to the distribution of shipments with respect to many manufacturers nationwide, as well as the relatively low cost of the heat pump compared to the well field and other associated costs.

Industry studies have shown that commercial projects add 22 jobs per project (40). This job creation rate for 71 commercial installations, combined with those created by the residential installations increases the jobs created or retained to over 1,600. Jobs may or may not be mutually exclusive (individual jobs or functions performed by separate individuals in a particular classification or position).

Mass economic impacts are shown in Figure 165.

Figure 165: Total Savings and Costs of GHP Systems in Minnesota

	Annual Savings per Building ($)	Incremental Unit Cost	GHP Projects	Estimated Annual Energy Savings ($)	Energy Savings			Total Incremental Cost	Incremental Installation Cost ($)
					kW	MWh	Therms		
Retrofit									
Residences	$ 760	$ 15,600	4,911	$ 3,732,337	1,637	-90,253	8,377,071	$ 76,609,073	$ 60,537,240
Offices	$ 15,507	$ 338,239	37	$ 568,605	-838	-6,338	1,172,050	$ 12,402,078	$ 10,827,211
Schools	$ 63,600	$ 1,024,745	11	$ 700,911	-728	-4,728	999,676	$ 11,293,231	$ 9,944,785
Subtotal			4,959	$ 5,001,853	71	-101,318	10,548,797	$ 100,304,383	$ 81,309,237
New Construction									
Residences	$ 472	$ 15,600	81	$ 38,257	0	-1,292	108,160	$ 1,264,050	$ 993,182
Offices	$ 11,534	$ 250,173	22	$ 254,761	-379	-3,055	538,586	$ 5,525,810	$ 4,750,258
Schools	$ 47,213	$ 1,024,745	1	$ 66,476	-110	-426	92,109	$ 1,442,840	$ 1,240,336
Subtotal			105	$ 359,494	-489	-4,774	738,855	$ 8,232,700	$ 6,983,776
Total			5,063	$ 5,361,347	-418	-106,092	11,287,653	$ 108,537,083	$ 88,293,013

3.4.4 Greenhouse Gas Emissions Impact

If the GHP installations described above are realized, both CO_2 and NO_x (including N_2O) emissions will increase. This increase is driven by the residential installations, which will cause greater increases in CO_2 emissions than the installations in the commercial and institutional sectors will save in CO_2 emissions. These increases in installations of GHP systems would have a negative impact on Minnesota's CO_2 emissions levels. These effects can be seen in Figure 166.

Figure 166: Statewide Greenhouse Gas Emissions Effect if Installations in Economic Development Discussion Are Realized

	GHP Projects	Annual GHG	
		Per Unit CO2 (lbs)	Total CO2 Reductions (Tons)
Retrofit			
Residences	4,911	-10,481	-25,736
Offices	37	88,727	1,627
Schools	11	354,046	1,951
	4,959		-22,158
New Construction			
Residences	81	-10,807	-438
Offices	22	56,918	629
Schools	1	266,657	188
	105		378
Total	5,063		-21,780

3.4.5 Barriers to Entry

Many barriers to entry exist for GHP systems. Some of the more prominent barriers are listed here, along with any data from this study that support the existence of the barrier.

High First Costs — First and foremost, GHP systems cost more than conventional HVAC systems. Many individuals and businesses installing HVAC systems install the lowest cost option, sometimes considering life cycle costs, and sometimes only considering first costs.

Cost Uncertainty — Further, there is a great deal of uncertainty with respect to installed costs of heat pump systems. Due to drilling requirements, heat pump installed costs are site specific, heavily dependent on local geology. A survey of local installers confirmed this dependence, and a survey of other studies as well as local installations showed a wide range of system costs.

Life Cycle Costs — All cases analyzed in this study show a benefit in energy costs. However, even the cases with the most savings on energy bills may not have a net savings when looked at from a life cycle cost perspective. For example, the Duluth area small office retrofit with a desuperheater saves an average of 38.1% on energy bills, but results in 4.4% higher life cycle costs over 15 years. This contradiction is one of the primary barriers to entry for GHPs. Buildings that benefit the most from the energy savings have inexpensive conventional alternatives, making them less appealing financially.

Low Incentives	A back of the envelope calculation was conducted, and incentives would need to be around 5x higher than the highest current incentives (or more) for small office GHP systems, for example, to be cost competitive. This level of incentive is highly unlikely to provide a positive result in a utility cost-benefit test. A lack of incentives large enough to cover the gap represents another barrier to entry. Current incentives offered by the large utilities in Minnesota are listed in Figure 163. The recent expiration of Federal GHP incentives is expected to have a further negative impact on the local GHP market due to this barrier. One survey recommended providing incentives to reduce the up-front cost differential to $3,000 or less for residential systems (40).
Local Utility Rates	GHP system energy cost comparisons to conventional systems are also highly dependent on utility rates, particularly in residential applications. One instance showed a GHP savings compared to the conventional system case range from 5.8% to 24.8% for the same building in the same location, depending on the utility rate structure. The comparisons shown in Figure 126 indicate where these savings variances occur.
Primary Fuel Costs	An investigation was conducted with respect to life-cycle costs of small residential buildings, comparing different heating fuels. The economic data shows that GHP systems are favorable when compared to oil and propone fuels, and are unfavorable to GHP system when compared to natural gas. An increase in natural gas prices by 40% relative to electricity prices would result in GHP systems becoming cost-effective on a life cycle cost basis. This sensitivity shows that natural gas prices impact the viability of GHPs in Minnesota more than incentives, and these prices need to be monitored over time if a GHP program is implemented
Low Education	Compared to conventional HVAC systems, GHP systems are relatively new. Many customers who may benefit from the systems may not know enough about them to select the system, or building designers and system installers throughout the state may not know enough about them to know how to properly design the systems when they can provide a benefit. The uncertainty in installed costs provides further reason for many people not to spend time learning about these systems.
No Organized Promotion	Studies have shown that active promotion of GHP systems can be effective in increasing the acceptance of the technology. Minnesota does not currently have an organized promotion strategy. Effective promotion programs include not only incentives, but also trade ally training, customer training, promotion of success stories, advertising to target customers, public communications, and an organized instructional reference tool (40). These facets of a promotional program will increase the installation capacity in the state at the same time as the program increases public awareness and acceptance of the technology.

These barriers to entry have resulted in a very low level of market penetration currently. According to information available from the EIA, only 0.4% of residential energy consumption and less than 0.05% of commercial and institutional energy consumption is provided by GHP systems (41). There are installers active in the state, listed in Appendix A.

3.5 Actions of Other States

A few other states have programs promoting GHP installations, with varying degrees of success. New York actively promotes GHP systems using incentives, trade ally training, customer training, promotion of success stories, advertising to target customers, public communications, and an organized instructional reference tool (40). North Dakota provides aggressive tax incentives to residents who install GHP systems, resulting in one of the highest penetration rates in the country in the adoption of this technology (42). Nevada also provides aggressive tax incentives, resulting in high percentages of GHP installations in both the commercial and residential sectors.

States that have high GHP installation rates are generally more rural states (ND, WY, NV, IA, etc), which may be a result of the noted price differential between natural gas and other heating fuel costs, especially LP and fuel oil, as well as the availability of excess land to install large wellfields.

4 Conclusions

From the results found in this study, the promotion and installation of ground source heat pumps in the state of Minnesota provides both benefits and challenges from a mass implementation perspective. In all cases investigated, the installation of GHPs reduces the energy costs required for operation of HVAC systems. By switching from natural gas heat to heat from an electric system, the installation of GHP systems increased both summer and winter peak demand in the mass implementation scenario.

In commercial and institutional buildings, greenhouse gas emissions are reduced. These reductions are less than 17%, and any effect on the statewide emissions will be minimal, even at projected potential installation levels. In residential buildings, greenhouse gas emissions show a net increase. If the projected potential installation levels are achieved, these increases in greenhouse gas emissions will likely outweigh the greenhouse gas reductions from the commercial and institutional installations. In all buildings, other pollutants, such as environmental toxins like mercury and particulate matter, and acid-causing pollutants like SO_2, are increased.

Comparing life cycle costs for GHP systems to conventional life cycle costs does not provide a definite benefit or detriment across all building types. Significant barriers to entry still exist for GHP systems. Energy price changes may change the situation in the future. The cost effectiveness of specific applications is unique and depends on factors such as the conventional alternative cost and type of system, GHP well field costs, occupancy, and fuel costs, to mention a few. A specific cost effectiveness analysis for each application will need to be completed to ensure the option with the greatest benefit is chosen.

5 Recommendations for Future Work

We are confident that the analysis presented in this study adequately and accurately represents the energy, economic, and environmental impacts for the specific buildings and system types presented, for the state of Minnesota given the assumptions used. However, due to the constraints of the study, the scope had to be limited in several aspects. Further study would provide an increased understanding into the effects, potential benefits, and performance of GHP and conventional systems within the state of Minnesota.

The thermal performance of GHP systems for this study was based on a single assumed pair of values for all building types: 14.1 EER cooling and 3.3 COP heating. In reality, the performance of different systems are likely to be better or not as good as assumed, due to variables in installation, site conditions, operating practices, and many others. No detailed investigation has been done regarding GHP performance for Minnesota installations. Thus, research on the actual field performance of GHP systems in Minnesota is needed to bridge this information gap.

It was necessary to limit the scope of the study to include only one large and one small representative building for each of the three climate zones within the state of Minnesota for each of the three building types. While this can provide an overview of the general behaviors of ground source heat pump characteristics within the state, it does not adequately assess the potential and limitations for the implementation of this technology in the state. Further analysis, including in depth studies of additional GHP applications, such as greenhouses and industrial processes, as well as other building types would allow further insight into the economic and environmental potentials.

The installed cost for GHP systems is highly variable. Individual building specifics such as local geology, cost of loop piping, costs of antifreeze, etc., can substantially affect the total installed cost of the system. In addition, determining a reasonable total installed cost for these systems is made more difficult by the large range of values presented in previous studies. The difficulty in comparing construction costs between studies is augmented due to the differences in system boundaries utilized in each study. In many studies, it is unclear if equipment such as ductwork, chilled and hot water loop piping, pumps, etc. is included in the installed costs. A further investigation into total installed costs of a variety of HVAC systems would be beneficial.

The scope of this study examined only a typical large and small building for each category, which therefore included a comparison using only one typical efficiency value for each of the conventional and GHP systems. Further analysis utilizing the costs and efficiencies of a variety of systems and efficiencies would allow a more precise comparison on savings which could be utilized to determine the most cost effective conditioning systems.

The scope included the comparison of emissions and economics to the most typical fuel source for water and space heating needs. Within the state of Minnesota, these needs are met by a combination of natural gas, electricity, LP, distillate oil, residual oils, and other sources. Further analysis, including both the economic and emissions comparison for a variety of fuel sources is recommended. In addition, the application of these emissions and economic comparisons would be recommended for the entire state of Minnesota based on percentages of facilities utilizing each fuel source.

In some cases, the implementation of GHP systems resulted in a net increase in both greenhouse gas emissions as well as other emissions. In other cases, the implementation of GHP systems resulted in a decrease in greenhouse gas emissions, but an increase in all other emissions. Changes in the electrical generation capability and source fuels will greatly affect the emissions for the GHP systems. Minnesota is strategically poised to be able to utilize wind, biomass, and other alternative fuels sources to decrease these specific emissions values. The specific emissions values were considered to be static in this study. Further analysis that included specific emissions values based on changes in the electrical generation mix over the course of the service life would provide additional insight into potential future emissions reductions.

Appendix A

Installers and Designers

Name	Company	City	Zip	Phone	Email	Web
Installers						
Joseph Heublein	Earth First Energy Systems	Altura	55910	507-523-2235		
Rick Fett	Harty Mechanical, Inc.	Austin	55912	507-437-8202		
Patrick Harty, Jr.	Minnesota Geothermal LLC	Austin	55912	507-437-8201	patrick.harty@minnesotageothermal.com	www.minnesotageothermal.com
Kent Schwen	Mid-American Energy Suppliers, Inc.	Baxter	56425	218-828-4375	info@mid-americanenergy.com	www.mid-americanenergy.com
Garret Sakry	Northern GroundSource, Inc.	Brimson	55602	218-848-2869	sakr0014@d.umn.edu	
Matthew Wangerin	Genz-Ryan Plumbing & Heating	Burnsville	55337	952-767-1000	mattw@genzryan.com	www.genzryan.com
Jerry Liffrig	Genz-Ryan Plumbing & Heating	Burnsville	55337	651-248-1137	jerryl@genzryan.com	
Brian Urlaub	Enertech, Inc.	Cottage Grove	55016	651-458-8846	burlaub@geocomfort.com	www.geocomfort.com
Warren Nelson	Summit Mechanical Service, LLC	Duluth	55806	218-728-9965	warren@summitmech.net	
Kevin Kaski	Summit Mechanical Service, LLC	Duluth	55806	218-728-9965	kevin@thermcosupply.com	www.thermcosupply.com
Steven Bruckelmyer	Summit Mechanical Service, LLC	Duluth	55806	218-728-9965	steveb@summitmech.net	
Jeff Ringenberg	Earth Energy Heating & Cooling, Inc.	Eyota	55934	507-421-3156	jaring07@msn.com	
Dale Benes	Benes Well Drilling Inc.	Grand Rapids	55744	218-326-5859		
Nicholas Schultz	Mineral Service Plus LLC	Green Isle	55338	320-238-0195		
Karl Butz	K P's Heating, Cooling & Refrigeration, Inc.	Hermantown	55811	218-525-4132	kpsheating@aol.com	
Gerald Grosjean	Geothermal Solutions	International Falls	56649	218-285-6155	ggrosjean@charter.net	
Rick Nash	Dedicated Geothermal LLC	Loretto	55357	763-432-4016	gbt-rdn1@msn.com	www.geoclip.com
Joseph Stevens	T. L. Stevens Well Company, Inc.	Maple Plain	55359	763-479-2272	joestevens@frontiernet.net	
John Henrich	Bergerson/Caswell, Inc.	Maple Plain	55359	763-479-3121 x204	JWH@BergersonCaswell.com	www.BergersonCaswell.com
Eric Bruns	Bruns Heating, Inc.	Marshall	56258	507-530-4551		
David Sheild	Inner Earth Energy	Minneapolis	55410	612-928-0625	daves@innerearthenergy.com	www.innerearthenergy.com
Bryon Martin	EPWE	Monticello	55362	763-295-4945	bryonm@charter.net	
Chris Prachar	D & E Heating, A/C, & Refrigeration	Mora	55051	320-679-9465	cj3161@msn.com	
James Strandlund	Strandlund Refrigeration	Mora	55051	320-679-2567	jim@strandlund.com	www.strandlund.com
Stephen Hartmann	Hartmann Well Company LLP	New Prague	56071	952-758-2202		
Kevin Hartmann	Hartmann Well Co. LLP	New Prague	56071	952-758-2202	kevnan@bevcomm.net	
James Schlichting	Jim's Heating & A/C	Pierz	56364	320-468-6742		
Scott Halvorson	H V A C Reps, Inc.	Rockford	55373	763-478-0400	scotth@hvacreps.com	
Robert Halvorson	H V A C Reps, Inc.	Rockford	55373	763-478-0400	bobh@hvacreps.com	
Wally Lewis	Bergerson/Caswell, Inc.	Rockford	55373	701-227-0841		

Name	Company	City	Zip	Phone	Email	Web
Installers						
Robert Thein	Thein Well Co., Inc.	Spicer	56288	320-796-2111	theinwell@tds.net	www.theinwell.com
Dean Boyer	Inner Earth Energy	Swanville	56382	320-547-9964	deanb@innerearthenergy.com	www.innerearthenergy.com
Bob Feely	Mark J. Traut Wells, Inc.	Waite Park	56387	320-251-5090	drill@trautwells.com	www.trautwells.com
Michael Steffl	Steffl Drilling & Pump, Inc.	Willmar	56201	320-235-8484	mike@waterwelldrilling.com	www.waterwelldrilling.com
David Prachar	Willow River Geothermal	Willow River	55795	218-372-3892	davidprachar@frontiernet.net	
Blaine Schatz	Warm Homes of Wright	Wright	55798	218-357-2911		
Designers						
Rick Nash	Dedicated Geothermal LLC	Loretto	55357	763-432-4016	gbt-rdn1@msn.com	www.geoclip.com
John Henrich	Bergerson/Caswell, Inc.	Maple Plain	55359	763-479-3121 x204	JWH@BergersonCaswell.com	www.BergersonCaswell.com

Appendix B

Utility Rates

Figure 167: Xcel Energy Electric Rates

	Summer Energy	Winter Energy	Summer Demand	Winter Demand
	($/kWh)	($/kWh)	($/kW)	($/kW)
Residential	$0.09076	$0.07776	N/A	N/A
Small General Service	$0.09076	$0.07776	N/A	N/A
General Service	$0.04221	$0.04221	$10.15	$6.81

Figure 168: Alliant Energy Electric Rates

	Summer kWh	Winter First 1000 kWh	Additional Winter kWh	Summer Demand	Winter Demand
	($/kWh)	($/kWh)	($/kWh)	($/kW)	($/kW)
Residential	$0.09286	$0.07664	$0.04775	N/A	N/A
General Service-Energy Only	$0.06880	$0.05350	N/A	N/A	N/A
General Service-Demand Metered	$0.04791	$0.04165	N/A	$8.88	$5.27

Figure 169: Minnesota Power Electric Rates

	First 50 kWh	Next 300 kWh	Additional kWh	All kWh	Demand
	($)	($/kWh)	($/kWh)	($/kWh)	($/kW)
Residential	$5.00	$0.04773	$0.07218	N/A	N/A
General Service-Energy Only	N/A	N/A	N/A	$0.06456	N/A
General Service-Demand Metered	N/A	N/A	N/A	$0.04612	$4.36

Figure 170: Ottertail Power Residential Electric Rates

	First 50 kWh	Next 450 kWh	Next 1000 kWh	Additional kWh
	($)	($/kWh)	($/kWh)	($/kWh)
Residential-City	$6.15	$0.08223	$0.05362	$0.05140
Residential-Rural	$7.10	$0.08223	$0.05362	$0.05140

Figure 171: Ottertail Power Commercial Electric Rates

	First 50 kWh	Next 1950 kWh	Additional kWh	kWh Over 200 kWh/kW	kWh Over 360 kWh/kW	First 100 kW Demand	Additional kW Demand
	($)	($/kWh)	($/kWh)	($/kWh)	($/kWh)	($/kWh)	($/kW)
General Service-With Demand-City	$8.45	$0.08574	$0.07134	$0.04999	N/A	N/A	N/A
General Service-Energy Only-Rural	$10.45	$0.08574	$0.07134	$0.04999	N/A	N/A	N/A
General Service-Demand Metered	N/A	N/A	$0.03066	N/A	$0.02792	$8.65	$7.30

Figure 172: Natural Gas Montly Customer Charge (Estimated from Center Point Energy)

Rate	Usage Limit (therms/month)	Monthly Charge
Residential	None	$ 6.50
Small Commercial	1,500	$ 9.5
Small Commercial	5,000	$ 15.0
Small Commercial	None	$ 35.0

Appendix C

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