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Ten-year Update: Emissions and Economic Analysis of Geothermal Heat Pumps in Wisconsin

UPDATE OF GEOTHERMAL ANALYSIS
PREPARED IN 2000

August 31, 2009

Energy Center Report Number 249-1

Ten Year Update: Emissions and Economic Analysis of Geothermal Heat Pumps in Wisconsin

Update of geothermal analysis prepared in 2000

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Acknowledgements

Energy Center of Wisconsin staff who contributed to this project include Scott Pigg, Lee DeBaillie, and Steve Kihm.

Thank you to all the contractors, engineers, and well drillers who participated in the cost survey. Thank you also to George Penn of Global Energy Options for allowing this study to build off of the raw data from the previous study.

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REPORT SUMMARY

Geothermal heat pump systems have emerged in recent years as a more energy efficient method of heating and cooling buildings of several different types. Their superior performance has been the driver behind exponential growth of these systems in Wisconsin in the last ten years. With strong growth, but a fledgling market share, geothermal systems could have the immediate potential to drive large savings in energy consumption and cost in the state – *if* they are demonstrated to be a cost-effective and environmentally-sound option for consumers, businesses, and the state as a whole.

Ten years ago, before the geothermal industry had seen much of its growth, the Energy Center of Wisconsin conducted a project with the Wisconsin Geothermal Association. We studied the emissions and economic impacts of geothermal systems in residential, commercial, and institutional sectors to determine their effectiveness compared to conventional systems. Since that study was released in 2000, there have been major changes in several of the key study parameters—most importantly changes in the cost of equipment installation and fuel, and changes in the emissions from the electricity used to operate the heat pumps. Alliant Energy commissioned an update to the original study to determine whether these changes have had a significant impact on any of the key conclusions of the earlier study.

In this update we used building performance calculations from the previous study, and applied new economic and emissions frameworks and data to those calculations to determine the current cost-effectiveness and environmental (emissions) impact of geothermal heat pump systems.

METHODOLOGY

In order to test the impacts of geothermal heat pump systems in Wisconsin, we used building models to compare these systems against conventional systems in otherwise identical buildings. Our basic approach was to take the energy analysis results from the original study, makes slight adjustments for equipment improvements (other building performance changes in the past 10 years are minor in comparison to equipment, emissions, and cost changes), and then run them through a completely new economic and emissions calculations. The same building types (and climate data) are therefore used from the previous study, as outlined in Table 1.

Building Types	Size
Large School	390,000 ft ²
Small School	69,000 ft ²
Office	69,000 ft ²
Community Development	185,000 ft ²
Residence	4 tons

Table 1. Building types studied.

Economics

The cost effectiveness of a geothermal system—as with any efficiency improvement—is a balance between initial cost and operating cost over time. We use the simple payback metric (often just called payback) and annual percent rate of return (ROR) to demonstrate the outcome of this balance. Our

preferred metric in this case is *rate of return* because simple payback does not capture many of the financial components that are important to consumers or policymakers.

Geothermal heat pump systems generally draw a premium for installation cost, primarily due to the large cost of the ground heat exchanger (GHX), which is the fundamental change from a conventional system. These cost differences are typically difficult to quantify, primarily because costs can vary widely depending on specific circumstances of each building. To determine a 'typical' cost difference for the purposes of this study, we surveyed 29 practitioners around the region, serving every type of building from small homes to large institutions.

The largest operating cost impact of geothermal systems is in energy savings. Energy costs were calculated using a median of current utility rates throughout Wisconsin for residential, commercial, and large commercial scenarios. Sensitivities to these medians were calculated to represent customers with atypical utility rates. Replacement and maintenance cost differences were added to round out the operating costs.

Emissions

Emissions impacts from choosing geothermal over a conventional system are considered for five pollutants:

- Carbon Dioxide – CO₂
- Sulfur Dioxide - SO₂
- Nitrous Oxides – NO_x
- Particulate Matter – PM₁₀
- Mercury – Hg

In the ten years since the previous study, emissions from regional electric power plants have changed due to pollutant controls, cleaner fuel sources, and new plants coming online. Perhaps more importantly, the accounting of emissions impacts based on marginal generation has received in-depth study by evaluators of the state's Focus on Energy program. We used these updated marginal emission factors in this study along with longer-standing emission factors for natural gas and propane.

RESULTS AND CONCLUSIONS

Several key conclusions concerning both economics and emissions can be drawn from the results of the study.

Economic Analysis

Of the two economic metrics used in this study, ROR is the only one that accounts for all the impacts of system selection (first costs and energy costs, plus replacement/salvage, taxes, depreciation, etc.). Based on ROR, geothermal heat pump systems appear to be cost effective across most scenarios. Rate of return was greater than 10% for all the scenarios except residential (for the office scenario it was generally 14% and schools approached 17%). For the residential scenario ROR was 9% if a horizontal GHX was possible; 8% for a vertical GHX. Though ROR has advantages for assessing heating and cooling systems, simple payback is still a common metric. In the school scenarios, the payback was 9-10 years. In the office scenario payback increased to 14-15 years—though payback is an especially poor metric for

private corporations due to tax effects. In the residential and community scenarios, payback varied from 19 – 24 years.

Incentives currently available at the federal and state (through Focus on Energy) levels improve the economics of all geothermal systems. In the community scenario, the federal tax credits increase the ROR to 13% (from 10%); this decreases the payback to 12 years (from 18). The school scenarios see only a modest improvement with incentives, because they are currently not eligible for federal tax incentives. The office scenario becomes extremely cost effective; ROR goes from 14% up to 43%. Similarly, the residential ROR (assuming horizontal installation) goes from 8% up to 35%. In both these cases, payback goes to just 4 years!

Variances in cost have a large impact on the results. In the residential scenario, natural gas costs vary from \$0.70/therm to \$1.30/therm, producing RORs from 5% to 13%. Geothermal installation for horizontal, residential systems sometimes had costs significantly below the media, which improved the ROR to 14% (a 12-year payback). Costs for vertical installations did not vary as much. In the office and schools scenarios the fuel prices had a smaller impact than in the residential scenario, but variability in installation costs had a much larger impact. We found cost differences as low as \$2.2/ft² for vertical commercial systems, resulting in RORs of 18% and 21% (9- and 7-year paybacks) in the office and school scenarios respectively. We also found cost differences as high as \$5.5/ft² which drove the ROR down to 11% in both scenarios.

Emissions Impacts

With increased focus on the societal and environmental impacts of energy use, it was important to consider the impact of geothermal heat pump energy use on the environment. Carbon dioxide emissions have been subject to the most scrutiny recently, due to their major role as a greenhouse gas. In the office and schools scenarios, geothermal heat pump systems decreased CO₂ emissions by 6 – 15%, consistently reducing emissions of the greenhouse gas in all cases. In the residential and community/multifamily scenarios, CO₂ emissions generally remained constant or increased slightly with inclusion of a geothermal heat pump system. However, in the case where the conventional system used electric heat instead of natural gas heat, CO₂ emissions were reduced by 40%.

Emissions of other pollutants follow differing trends, based upon their relative emission rates when shifting from gas heat to electrically driven heat pumps. Mercury emissions are always decreased with adoption of geothermal heat pump systems. Particulate matter (PM₁₀) and SO₂ are emitted at higher rates in the production of electricity and increase with adoption of geothermal in all scenarios except the office scenario and electrically-heated residences. The impact on NO_x varies widely depending on the building type. For residential building types, if marginal generation from renewables increases in the future, the emission impacts of geothermal systems become more favorable (this is primarily true in residential building types because emission impacts in these buildings depends on the shift from from gas heat to electrically driven heat pumps).

Other Conclusions

Results of this study are dependent on many variables that can be very specific to a given project. This analysis should be generally helpful, though, in determining the applicability of geothermal to typical projects, the treatment of geothermal in efficiency and emissions policies, and the effects of key variables

in both of these areas. The sensitivities modeled here can also be used to determine how the results should be considered as emissions factors and costs change in the future.

INTRODUCTION

Geothermal heat pump systems have emerged in recent years as a more energy efficient method of heating and cooling buildings of several different types. Their superior performance has been the driver behind the exponential growth of these systems in Wisconsin in the last ten years (Figure 1). However, they often have a higher first cost than other systems, leading to a market share below 2% in residential heating and cooling¹ (not likely to be any higher in commercial markets). With recent growth, but a fledgling market share, geothermal systems could have the immediate potential to drive large savings in energy consumption and cost in the state – *if* they are demonstrated to be a cost-effective and environmentally-sound option for consumers, businesses, and Wisconsin as a whole.

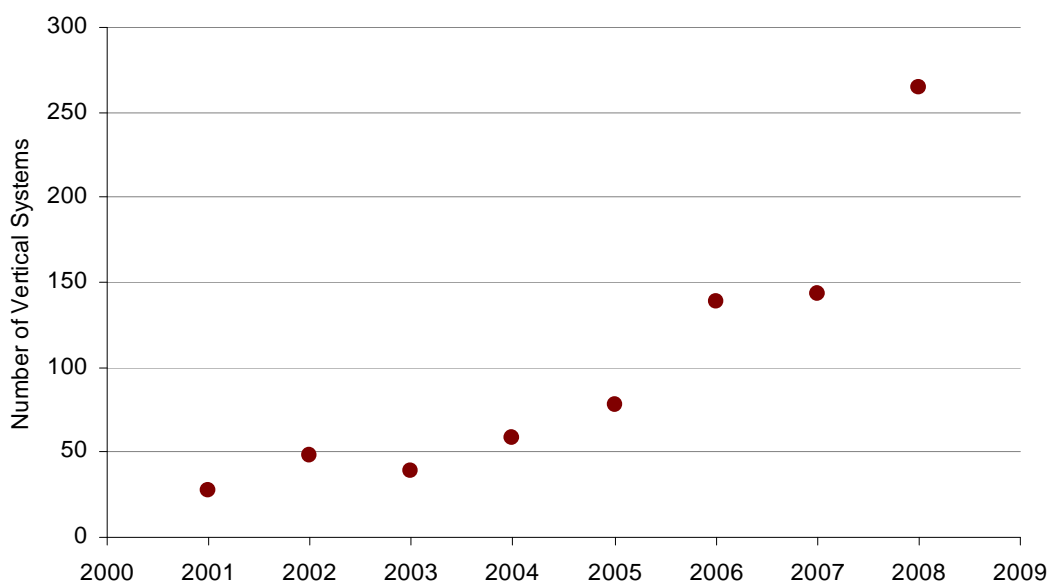


Figure 1. Number of vertical geothermal systems approved in Wisconsin from 2001 to 2008. Horizontal and open systems are not tracked by the state, but anecdotally suggest significant growth as well.²

BACKGROUND AND OBJECTIVE

Ten years ago, before the geothermal industry had seen much of its growth, the Energy Center of Wisconsin conducted a project with the Wisconsin Geothermal Association. We studied the emissions and economic impacts of geothermal systems in residential, commercial, and institutional sectors to determine their effectiveness compared to conventional systems. That study recognized that other research nationwide had shown significant benefits from geothermal systems in some applications, but the nascent Wisconsin geothermal industry was lacking research into the region-specific impacts driven by

¹ *Emerging Technologies Report: Residential Ground Source Heat Pumps*, American Council for an Energy Efficient Economy, 2007. http://www.aceee.org/emertech/2006_GSHP.pdf

² Correspondence from Wisconsin Department of Natural Resources.

local climate, costs, and emissions profiles. Our earlier study concluded that geothermal systems had potential for significant financial and environmental benefits (driving the growth in Figure 1) in certain Wisconsin markets, while facing more challenging economics in other markets, including much of the residential sector³.

Since that study was released in 2000, there have been major changes in several of the key study parameters. Natural gas prices have risen steadily in that time; electric prices also have risen but more slowly. Installation costs have seen upward pressure from increases in material costs, energy costs, and consumer demand for geothermal systems. But this has been balanced somewhat by a growth in the number of industry practitioners with installation experience in the state. Emissions from the regional electrical grid have decreased⁴, and could potentially decrease more in the near future as renewable portfolio standards are enforced.

Additionally, equipment efficiencies have seen some changes, new data has been released on system maintenance costs, and new federal tax credits now deserve consideration in making the systems affordable in Wisconsin.

For these reasons, Alliant Energy funded an update of the 2000 study. This updated study maintains relevant technical data from the first report (including much of the building energy analysis), but revises the models to include all the changes mentioned above in the hope of determining the current state of geothermal systems in Wisconsin. Some of the questions we hoped to answer included:

- Would the residential market still face ‘tenuous’ economics—as professed in the last study? Would the commercial market look even more cost effective, or show problems as well?
- What are the current costs of installing and maintaining geothermal systems in comparison to conventional systems?
- What are the potential impacts of the increase in renewably-generated electricity on geothermal?
- How (if at all) should Wisconsin and/or Midwestern energy efficiency programs treat geothermal heat pump systems?

This update provides information to assist in answering all these questions.

³ *Emissions and Economic Analysis of Ground-Source Heat Pumps in Wisconsin*, Global Energy Options, July 2000. This initial project was part of a series of projects aimed at utilizing geothermal heat pump systems effectively in Wisconsin. Other projects included studying the viability of a geothermal association (now the Wisconsin Geothermal Association) and a series of in-depth case studies of some of the early residential geothermal systems in Wisconsin.

⁴ *Quantifying Environmental Benefits of Focus on Energy: Emission-rate Estimates 2002 to 2006*, PA Knowledge Limited, 2008.

METHODOLOGY

In order to test the impacts of geothermal heat pump systems in Wisconsin, we used building models to compare these systems against conventional systems in otherwise identical buildings. Economic and emissions comparisons between the two system types can then be made based on modeled energy usage.

The biggest changes that have occurred in this analysis since the previous study are in the area of economic and emissions calculations. While the building modeling also could benefit from some updates, it would result in fewer changes, and technical issues would make revising the original models an intensive, clumsy process. The basic approach for this update therefore takes the energy analysis results from the original study, makes slight adjustments for equipment improvements, and then runs them through a completely new economic and emissions calculations. The one exception to this methodology was the residential scenario, in which actual building data was used (more details below).

Because we employed the building analysis from the original study, we also used the same climates and building types in our update (as outlined in Table 2). These building types (other than perhaps the community/multifamily scenario) were and continue to be popular choices for applying geothermal systems. In total there were 13 building scenarios studied: each of the first four buildings were studied in three climates, and the residential scenario was studied as a statewide average.

Building Types	Size	
Large School	390,000	ft ²
Small School	69,000	ft ²
Office	69,000	ft ²
Community Development	185,000	ft ²
Residence	4	tons

Climates	HDD	CDD
Madison	7366	554
Green Bay	8169	416
Eau Claire	8417	505

Table 2. Different climates and building types studied. HDD = Heating Degree Days, CDD = Cooling Degree Days.

BUILDING ENERGY USAGE

Building energy usage for the first 12 scenarios was originally calculated based on building energy simulations by CDH Energy and Oak Ridge National Laboratory. These organizations used TRNSYS and DOE2 software to complete energy models of each building: DOE2 was used for office and schools, TRNSYS for community/multifamily. Both software packages are considered highly reliable in the simulation field, and are still in wide use today.

The residential scenario was analyzed with actual energy usage data. This data came from a 1997 Energy Center project in which heat pumps were installed and monitored at seven residences in Wisconsin.⁵ These homes were heated and cooled by geothermal heat pump systems. We determined that the detailed data collected from these homes was a more representative sample of data than the one model created in the 2000 study.

Detailed information on the simulation models and homes studied (including HVAC systems) can be found in the original reports. Following are brief summaries, beginning with descriptions of the HVAC systems. The energy usage results were modified slightly (a few percent) to account for changes in the typical equipment efficiencies currently being installed in Wisconsin buildings. We used average equipment efficiency data from EIA where available, and filled in the gaps with Energy Center staff experience on Wisconsin projects. Heating, ventilating, and air conditioning energy was separated from other building energy, so this modification only required an estimation of the percentage of HVAC energy that is consumed by heating and cooling equipment (vs. fans and pumps, which were left unchanged). The resulting average system cooling efficiencies are shown in Table 3.

System EER, Cooling (with fans/pumps)

	Conventional	Geothermal
Large School	8.6	13.1
Small School	8.5	10.9
Office	8.6	12.1
Community	12.4	14.1
Residential	12.0	13.9

Table 3. System average cooling energy efficiency ratio (EER, in Btu/h/W) for each building type, including power consumption from distribution equipment like fans and pumps.

It is convenient to list heating efficiency for the equipment without fans and pumps, because the conventional systems operate using natural gas (electric usage from fans/pumps is not easily integrated). These average efficiencies are listed in Table 4.

Heating Equip. Efficiency (no fans/pumps)

	Conventional: Furnace/Boiler Eff.	Geothermal: Heat Pump COP
Large School	78%	3.6
Small School	78%	3.7
Office	78%	3.6
Community	92%	3.3
Residential	92%	3.5

Table 4. Average efficiency of heating equipment for each building type. For furnaces and boilers this represents the combustion efficiency, for geothermal heat pumps it represents the coefficient of performance (COP); both are given at design conditions.

⁵ *Enhanced Residential Heat Pumps: Long Term Data Summary*, Prepared by CDH Energy, Energy Center of Wisconsin, October 1998.

For the school and office scenarios, the conventional system was modeled as a variable-air volume system with hot water reheat and cooling provided by a chiller. As the equipment efficiencies were adjusted for the current study, the commercial cooling equipment for the office and small school was adjusted to match the efficiency of a code-minimum chiller system, which can be considered similar to the efficiency of above-average rooftop units. For the commercial buildings the geothermal system is assumed to be a centralized ground heat exchanger (GHX) with heat pumps distributed throughout the building, one in each HVAC zone. Note that the office and small school were modeled with hot water preheat for makeup air in both conventional and geothermal cases. This is often more effective than attempting to warm frigid air with heat pumps, and reduces the first cost of the GHX (this first cost adjustment is made after the nominal system costs are calculated in Table 7).

For the residential and community/multifamily cases, the conventional system consists of a high efficiency condensing furnace and central air conditioning system. The geothermal system consists of the same forced air approach with a geothermal heat pump providing heating and cooling, and backup electric resistance heat.

Water heating in the office and school scenarios was assumed to be gas-fired in all cases. The residential scenarios were also assumed to be gas, but a heat pump desuperheater was included in the geothermal case. The community/multifamily development was assumed to have gas-fired hot water in the conventional case and heat pump desuperheaters with back-up electric water heat in the geothermal case; electric water heat is common for multifamily geothermal.

The buildings and systems studied were all based on projects that have actually been built, and therefore reflect realistic architectural and systems choices. Additionally, in all cases except the large school, data from actual buildings—including energy consumption—was studied extensively to inform the models/analysis. A further description of each is given below:

Large School. The model is based on the actual design of the Fond Du Lac High School in Wisconsin, which is a 390,000 ft² building that includes all major amenities such as a gymnasium and auditorium.

Small School. The model is based on an actual 69,000 ft² school building in Nebraska with a geothermal system that has been heavily studied by Oak Ridge National Laboratory (ORNL) and compared to other school systems. The building model was modified to reflect Wisconsin building codes.

Office. The model is based on an actual 69,000 ft² office building in Tennessee that has been heavily studied by ORNL and analyzed for different HVAC system options. The building model was modified to reflect Wisconsin building code.

Community/Multifamily Development. The model is based on a community development in Louisiana that underwent a full retrofit from conventional residential system to geothermal; the impact of the retrofit was heavily studied by ORNL. The community consists of single and multi-family homes. There is a total of 185,000 ft² of space made up of 142 separate units (each with their own mechanical system). The community model was modified to reflect Wisconsin building code. Note that this scenario generally results in higher heating loads than in the residential scenario. In the residential scenario, data was used from actual geothermal homes in Wisconsin and suggests that those homes having slightly better thermal performance than code.

Residential. The residential energy usage data requires further discussion as it is not based directly on the modeling discussed in the earlier report. As mentioned above, this building is based on an average of seven homes in Wisconsin, all with geothermal heat pump systems. The heating and cooling electricity usage for the geothermal case was taken directly from this collected data, with slight modification for the improvement in heat pump efficiency, as with the other scenarios. The hot water usage for the geothermal case was decreased by 31% from the conventional case for the usage of a desuperheater; this 31% savings is calculated based on measured data in that study.

The conventional case in the residential scenario relied on a spreadsheet model. The heating and cooling loads in the heat pump homes were tracked in detail through flow and temperature measurements on both the air and water side of the units. Natural gas usage was calculated based on those heating loads and the condensing furnace efficiency (Table 4), and 190 therms annually for water heating (average for Wisconsin single family homes). Electric usage for cooling was based on those cooling loads and a nominal average seasonal energy efficiency ratio (SEER) of 13 kBtuh/kW, adjusted for Wisconsin's climate⁶, plus the same blower consumption from the geothermal case. Additionally, electricity was added for blower consumption during heating mode by modifying the heating blower consumption from the geothermal homes to account for the higher heating temperature of a conventional system (which results in lower blower consumption).

EMISSIONS

A major component of this study was to determine the emissions impacts from choosing geothermal over a conventional system. Five pollutants were considered:

- Carbon Dioxide – CO₂
- Sulfur Dioxide - SO₂
- Nitrous Oxides – NO_x
- Particulate Matter - PM₁₀
- Mercury – Hg

Emissions from both natural gas and electricity are important here; electricity is discussed first. In the ten years since the previous study, emissions from regional electric power plants have changed due to pollutant controls, cleaner fuel sources, and new plants coming online. Perhaps more importantly, the accounting of emissions impacts based on *marginal generation* has completely changed the way emission reductions from efficient technologies are calculated. This new, better understanding of accounting affects the emissions impacts in two ways: 1) emissions impacts are calculated based on all plants connected to the grid that serves Wisconsin and 2) emissions impacts are calculated based on *marginal* plant (the last power plant to be 'turned on') emissions.

The first point is derived from well accepted accounting tools⁷ for emission reductions which specify that the best geographic region to consider when counting emissions is the entire electrical grid to which a

⁶ Fairey, P., D.S. Parker, B. Wilcox and M. Lombardi, "Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps." ASHRAE Transactions, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, June 2004.

⁷ Greenhouse Gas Protocol Initiative: <http://www.ghgprotocol.org/>

building is connected. The second point is that emissions reductions from a technology like geothermal actually occur by allowing the marginal plant to decrease its production. Therefore, emissions reductions are best calculated based on statistical measures of a typical *marginal* plant throughout the year, *not* the average plant emissions for the region.

To meet these two ends, emissions factors are based on evaluation studies of Focus on Energy, Wisconsin's public benefits program. Evaluators of Focus on Energy have done extensive modeling of plant activity on Wisconsin's grid (which includes a lot of generation outside Wisconsin's borders). This modeling aims to calculate what the average marginal emissions rates are for the state's electricity. The results of this modeling are given in Table 5. Particulate matter (PM₁₀) is included in this table but is not modeled in Focus on Energy evaluations; it is based instead on data compiled by the Wisconsin Department of Natural Resources.⁸

	Electricity lbs/MWh
Particulate matter	0.43
CO ₂	1700
NOx	2.9
SOx	2.7
Mercury	1.5E-08

Table 5. Average marginal emissions rates for Wisconsin electricity.⁹

To maintain consistency the natural gas emissions rates are also based on Focus evaluation results; these are derived from EPA calculated emissions for on-site combustion of gas (Table 6).

	Natural Gas lbs/1000 therms
Particulate matter	0.0
CO ₂	11760
NOx	9.8
SOx	0.059
Mercury	0.000026

Table 6. Average emission rates for natural gas.¹⁰

Emissions impacts from natural gas depend heavily on the emissions trade-off from natural gas heating to heating with the electrically driven heat pumps, though the greater performance in both heating and cooling also has an impact. In all cases, cumulative energy usage is simply multiplied by the emission rates above to determine the total emissions from a given building scenario.

⁸ Wisconsin Department of Natural Resources historical air emissions information; http://dnr.wi.gov/air/emission/historical_emissions/index.htm

⁹ *Quantifying Environmental Benefits of Focus on Energy: Emission-rate Estimates 2002 to 2006*, PA Knowledge Limited, 2008.

¹⁰ *Focus on Energy Evaluation Semiannual Report*, PA Knowledge Limited, April 2009.

ECONOMICS

The cost effectiveness of a geothermal system—as with any efficiency improvement—is a balance between initial cost and operating cost over time. Metrics of simple payback (often just called payback) and annual percent rate of return (ROR) are used to demonstrate the outcome of this balance. Our *preferred metric in this case is rate of return* because simple payback does not capture many of the financial components that are important to consumers or policymakers, and is difficult to compare to other business decisions. Rate of return is calculated as the discount rate at which the present value of future cost savings equals the added first cost of the technology. A consumer or business may compare this number to some required ROR to determine cost-effectiveness (for example, if a geothermal system yields an 11% rate of return for a business, they may compare the 11% favorably to a business loan they can get at 8%). The ROR calculation in this study is evaluated for a 20-year lifetime. The cost inputs to this calculation are discussed below, beginning with the initial equipment costs.

Equipment Costs

Geothermal heat pump systems generally draw a premium for installation cost, primarily due to the large cost of the GHX, which is the fundamental change from a conventional system. The GHX cost is directly dependent on its size, which is a function of both the size of the building loads as well as the heat transfer properties of the geology at the building site. There is also some difference in the cost of the rest of the equipment, but it is minor (in fact it's often unclear whether it should be an increase or decrease). These cost differences are typically very difficult to quantify, primarily because costs can vary widely depending on specific circumstances of each building—everything from building load types, to air quality constraints, to local geology and local labor rates. In this study we make a fundamental assumption, however, that an average or median cost difference between geothermal and conventional systems over a wide range of buildings can be used to draw a *useful comparison* of the two systems.

To determine this typical cost difference, we surveyed 29 practitioners around the region, serving every type of building from small homes to large institutions. Respondents included drillers, engineers, and contractors. Cost *difference* information was collected for both bid projects and actual building installations. For actual building installations the difference between systems was calculated based on an estimate or alternate bid for the other system. This allows system costs to be compared for specific buildings, which eliminates the statistical problems of comparing two completely different sets of buildings (one group with geothermal and another group without). Building size—in terms of area or tonnage—was used to correlate all the cost data to determine cost differences for the five building scenarios in this study.

The building scenarios being considered here are assumed to be *new construction or major remodel* of the building. For HVAC replacement only, the cost differences would likely change significantly. The costs of such a replacement are so specific to the building and system that a meaningful look at replacement cost differences would require an effort beyond the reach of this study.

The largest data set available was cost difference data for typical commercial installations, assuming a vertical GHX. This data is summarized in Figure 2. Note that as expected for the reasons stated above, cost data is highly variable. But ranking the data by percentile helps us to determine what the most 'typical' cost would be. A given project could use this data to determine how their financial outcome will vary from the results of this study by scaling the costs accordingly. Projects would scale *up* from the

median to account for poor geology for drilling or conductivity, if a central control system is installed that is more complicated than needed, or if the equipment is not carefully sized (typical rules of thumb and/or safety factors can lead to greatly oversized GHXs). The median cost difference in this case is \$3.95/ft².

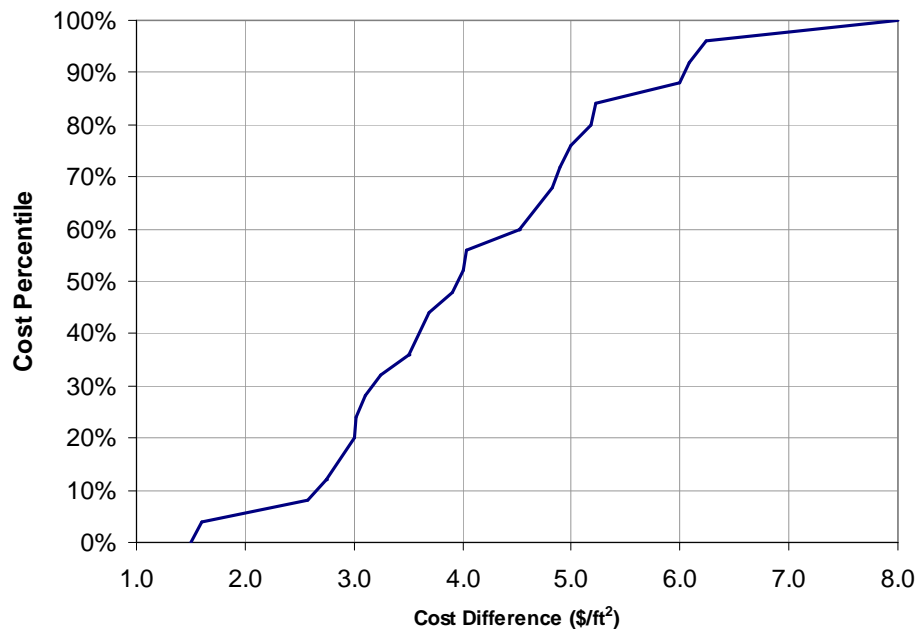


Figure 2. Summary of survey response data for cost difference between commercial geothermal and conventional systems for new construction or major building remodeling projects.

Evidence supported distinguishing the large school costs from the more moderately sized small school and office. Anecdotally, this difference is driven by economies of scale in drilling. Once a driller is set up at a site, it is cheaper *per well* for him to drill 100 wells than 8. So we kept large installations in a separate, smaller data set. This data set was also used to inform costs for the community/multifamily scenario, in which a very large GHX would be installed for the entire community.

For the residential scenario data collected included both horizontal and vertical GHX installations. The base case studied in this report considers horizontal geothermal installations, which are preferred if there is land available on site. An alternate case is also given for sites where vertical installation is required. Costs for residential systems in the survey were more accurately given by practioners per ton than per ft², so the analysis for a residential system is done per ton rather than per ft²; the median cost difference in this case is \$2050/ton. The homes studied could be considered fairly average (with an average of 4 tons), and financial results should be reasonable for a large range of Wisconsin homes (1500 – 3000 ft²). It should be noted that with geothermal systems it is extremely important to conduct actual sizing calculations for a given home and not simply use rules of thumb; the cost effectiveness of geothermal is severely weakened if systems are oversized.

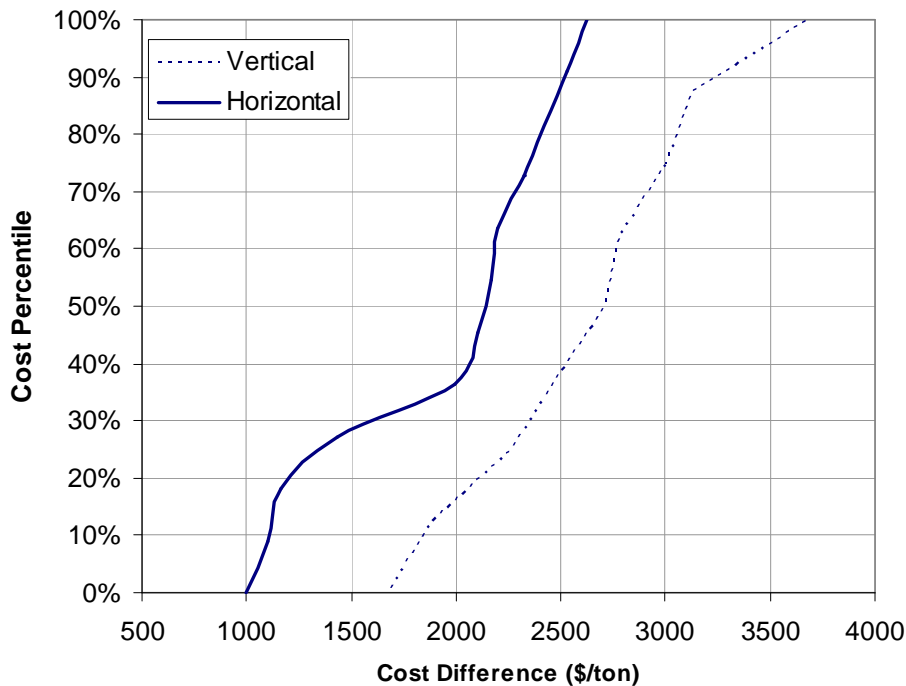


Figure 3. Summary of survey response data for cost difference between residential geothermal and conventional systems, for new construction and major home remodeling projects.

A final adjustment is required for a slight reduction in the size—and therefore construction cost—of a commercial or institutional building with a geothermal system. This size reduction is due to the fact that several conventional pieces of mechanical room equipment (boilers, air handlers, major ducts) are eliminated or severely reduced in size. Since this is difficult to quantify, we estimate a conservative impact of 0.5% reduction in building area (equipment rooms are generally a few percent of the total space; the previous study assumed 1% reduction overall). This difference is applied to the schools and office building. There is no reduction in a residential application.

The final resulting cost differences used in this study are summarized in Table 7.

Cost Difference Assumed in Study	
Large School	\$3.00/ft ²
Small School	\$3.45/ft ²
Office	\$3.45/ft ²
Community	\$3.00/ft ²
Residential	\$2100/ton

Table 7. Cost differences between geothermal and conventional systems, as used in this study.

The current economic environment may be responsible for low cost estimates for both system types, but the difference between them (which drives all the results of this study) is likely to remain similar. In any case, *construction costs in actual buildings throughout the state may vary significantly from these estimates for the range of reasons discussed at the beginning of this section.*

Operating Costs

The largest operating cost impact of geothermal systems is in energy savings. The costs of energy are calculated using a median of current utility rates throughout Wisconsin for residential, commercial, and large commercial scenarios. In this study, the median is taken from the three largest investor owned utilities (Wisconsin Public Service, Alliant Energy, and We Energies) and a small sample of rural cooperatives and municipal utilities. The resulting assumed utility rates are summarized in Table 8.

Rate	Scenarios	Electric Cons. (\$/kWh)		Demand (\$/kW)		Nat. Gas (\$/therm)
		Peak	Off-Peak	Monthly	Ratchet	
Residential	Residence, Comm. Dev.	\$0.11	\$0.11			\$1.00
Commercial	Office, Small School	\$0.07	\$0.05	\$8.48	\$1.72	\$0.88
Large Commercial	Large School	\$0.07	\$0.04	\$8.54	\$2.05	\$0.88

Table 8. Utility costs assumed in the base case of this study.

These assumed fuel costs have a huge effect on the results, because a geothermal system relies heavily on a switch from gas-driven heating to electricity-driven heating. When applying the results of this study to a particular scenario or region of the state, consider the gas and electric costs in that region relative to those in this study and adjust accordingly. Price sensitivities are included in the results section as a guide.

These fuel costs will of course inflate over the course of the 20 years being studied. Fuel cost inflation rates are those predicted by the Energy Information Administration (<http://www.eia.doe.gov/>) as part of the Federal Energy Management Program, and are summarized below (inflation rates shown are nominal).

- Electricity cost inflation: 1.7%
- Gas cost inflation: 3.1%

Another difference that must be incorporated into the life cycle analysis is maintenance costs. Geothermal heat pump systems are widely considered to have lower maintenance costs than conventional systems due to several characteristics: no exposed equipment, simplified controls, less air handling equipment, etc. Research has shown a wide range of different potential savings from this advantage. Only four U.S. studies from the last ten years directly compared maintenance costs in similar buildings with geothermal systems and the conventional systems considered in this study. The average demonstrated annual savings from those studies was \$0.10/ft². This is the value assumed in this study. For the residential system, average service frequency was added for residential central air systems; the heat pump maintenance was assumed roughly equal to the maintenance for a typical conventional furnace (there is no data to support any added or decreased costs).

The different pieces of equipment studied here also have different expected lifetimes, so equipment replacement costs must be factored into the life-cycle cost. Equipment lifetimes are based on ASHRAE published data¹¹. Residential air conditioners, rooftop equipment, chillers, and air handlers are expected to last 15 years, after which they will be replaced. Residential furnaces are expected to last 18 years. And heat pumps are expected to last 19 years. The GHX is expected to last the life of the building, and all other equipment is assumed to last the 20-year study life.

¹¹ 2003 ASHRAE Handbook: HVAC Applications, American Society of Heating, Refrigeration, and Air-Conditioning Engineers, 2003.

RESULTS

The results of the base cases for all five building scenarios are presented below, along with discussion of any interesting results specific to the building scenario. Sensitivity cases are presented following these results. Finally, we discuss results trends and conclusions that cut across all scenarios.

LARGE SCHOOL

Results for the large school (390,000 ft²) scenario are given for each climate in Table 9. In general, the ROR on a geothermal system is well above borrowing rates, at 15-17%. This is due in large part to an operating cost savings of about \$0.30/ft² (22% of annual energy cost), which leads to a payback of only 9-10 years.

Carbon emissions from large schools decrease significantly with the adoption of geothermal; CO₂ dropped by about 2 lbs/ft² annually in this example. Mercury and NO_x emissions decrease as well; SO₂ and PM₁₀ increase due to the increased reliance on electricity.

Annual Energy Savings

	Electricity		Demand		Natural Gas	
	kWh	kWh/ft ²	kW	W/ft ²	therms	therms/ft ²
Eau Claire	-117,554	-0.30	436	1.12	92,104	0.24
Green Bay	-158,740	-0.41	255	0.65	100,633	0.26
Madison	-124,091	-0.32	300	0.77	77,224	0.20

Economics

	Incremental Install. Cost	Oper. Cost Savings	Oper. Cost Savings	Simple Payback	Rate of Return	Simpl. After Tax ROR
	\$	\$	\$/ft ²	years	%	%
Eau Claire	1,170,000	127,913	0.33	9.1	16.7	---
Green Bay	1,170,000	128,321	0.33	9.1	16.8	---
Madison	1,170,000	112,066	0.29	10.4	15.5	---

Annual Emissions Savings

	CO ₂ lbs	CO ₂ lbs/ft ²	PM ₁₀ lbs	NO _x lbs	SO _x lbs	Mercury lbs
Eau Claire	883,308	2.3	-51	565	-313	0.002
Green Bay	913,582	2.3	-68	531	-424	0.003
Madison	697,195	1.8	-53	401	-332	0.002

Table 9. Results of the Large School (390,000 ft²) scenario.

SMALL SCHOOL

Results for the small school (69,000 ft²) scenario are given for each climate in Table 10. Small school economics are similar to the large school, but slightly weaker due to economies of scale. The annual

operating cost savings are still about \$0.30/ft² (18% of annual energy cost), but with slightly higher drilling costs the ROR is 15-16% and payback is 10-11 years.

Emissions follow a similar trend to the large school: 2-3 lbs/ft² per year in CO₂ savings and savings of Mercury and NO_x emissions; both SO₂ and PM₁₀ increase.

Annual Energy Savings

	Electricity		Demand		Natural Gas	
	kWh	kWh/ft ²	kW	W/ft ²	therms	therms/ft ²
Eau Claire	-13,392	-0.19	-24	-0.35	16,929	0.25
Green Bay	-12,534	-0.18	-31	-0.45	17,544	0.25
Madison	-14,608	-0.21	-22	-0.32	15,519	0.22

Economics

	Incremental Install. Cost	Oper. Cost Savings	Oper. Cost Savings	Simple Payback	Rate of Return	Simpl. After Tax ROR
	\$	\$	\$/ft ²	years	%	%
Eau Claire	198,375	19,227	0.28	10.3	15.8	---
Green Bay	198,375	20,407	0.30	9.7	16.3	---
Madison	198,375	17,913	0.26	11.1	15.2	---

Annual Emissions Savings

	CO ₂	CO ₂	PM ₁₀	NO _x	SO _x	Mercury
	lbs	lbs/ft ²	lbs	lbs	lbs	lbs
Eau Claire	176,316	2.6	-5.8	127	-35	0.0004
Green Bay	185,014	2.7	-5.4	136	-33	0.0004
Madison	157,669	2.3	-6.3	110	-39	0.0004

Table 10. Results of the Small School (69,000 ft²) scenario.

OFFICE

The results for the office scenario (69,000 ft²) are given for each climate in Table 11. An additional economic metric, simplified after-tax rate of return is also given for this scenario. An office represents the only building that is almost always owned by a taxable, private corporation. Such a corporation pays taxes that have a significant effect on operating costs (decreasing operating savings) and also sees the tax benefits of equipment depreciation. This value is considered ‘simplified’ because the tax code actually has very complex effects on a corporation; this scenario simply assumes a 38.6% marginal total tax rate and 5-year MACRS depreciation (geothermal equipment is in the IRS’ 5-year category).

Operating cost savings are \$0.20/ft² for the office; this savings comes from both electricity and gas savings (due to the larger amount of cooling). This is unlike the schools scenario where savings are entirely from gas. The ROR, including taxes, was as high for the office scenario as it was for schools, at about 14%. The simple payback is slightly longer at 14-15 years.

Due to the combination of electric and gas savings, *all* emissions decrease with the adoption of geothermal in an office scenario. Carbon dioxide decreases by 1 lbs/ft² per year, and all other emissions decrease as well.

Annual Energy Savings

	Electricity		Demand		Natural Gas	
	kWh	kWh/ft ²	kW	W/ft ²	therms	therms/ft ²
Eau Claire	1,147	0.02	34	0.49	6,006	0.09
Green Bay	1,339	0.02	28	0.40	6,825	0.10
Madison	9,404	0.14	41	0.59	5,275	0.08

Economics

	Incremental Install. Cost \$	Oper. Cost Savings \$	Oper. Cost Savings \$/ft ²	Simple Payback years	Rate of Return %	Simpl. After Tax ROR %
Eau Claire	206,310	13,934	0.20	14.8	12.7	13.7
Green Bay	206,310	14,614	0.21	14.1	13.0	13.9
Madison	206,310	14,155	0.21	14.8	12.8	13.7

Annual Emissions Savings

	CO ₂ lbs	CO ₂ lbs/ft ²	PM ₁₀ lbs	NO _x lbs	SO _x lbs	Mercury lbs
Eau Claire	72,578	1.1	0.5	62	3	0.0002
Green Bay	82,536	1.2	0.6	71	4	0.0002
Madison	78,015	1.1	4.0	79	26	0.0001

Table 11. Results of the Office scenario; 69,000 ft² of office space.

COMMUNITY / MULTIFAMILY DEVELOPMENT

The results for the community/multifamily development scenario (185,000 ft²) are given for each climate in Table 12. Operating cost savings are about \$0.16/ft², leading to an ROR of 10% (with a simple payback of 18-19 years). This generally compares favorably to mortgage rates.

Emissions tend to increase in the community/multifamily scenario due to the relatively large heating load being converted from gas-fired furnaces to electrically driven heat pumps. Carbon dioxide emissions increased by about 0.6 lbs/ft².

Many community developments and multifamily buildings in Wisconsin do rely on propane or electric resistance heat. These cases were not modeled in this scenario, but they were modeled in the residential scenario. That scenario can be used as guidance for the savings trends that can be expected for all-electric and propane homes in Wisconsin, as the two building types are similar.

Annual Energy Savings

	Electricity		Demand		Natural Gas	
	kWh	kWh/ft ²	kW	W/ft ²	therms	therms/ft ²
Eau Claire	-633,703	-3.43	-523	-2.83	80,420	0.43
Green Bay	-605,035	-3.27	-413	-2.23	77,901	0.42
Madison	-568,292	-3.07	-311	-1.68	74,113	0.40

Economics

	Incremental Install. Cost	Oper. Cost Savings	Oper. Cost Savings	Simple Payback	Rate of Return	Simpl. After Tax ROR
	\$	\$	\$/ft ²	years	%	%
Eau Claire	555,000	29,213	0.16	19.0	10.1	---
Green Bay	555,000	29,848	0.16	18.6	10.1	---
Madison	555,000	30,101	0.16	18.4	10.1	---

Annual Emissions Savings

	CO ₂	CO ₂	PM ₁₀	NO _x	SO _x	Mercury
	lbs	lbs/ft ²	lbs	lbs	lbs	lbs
Eau Claire	-131,555	-0.7	-272	-1031	-1713	0.0020
Green Bay	-112,438	-0.6	-260	-973	-1635	0.0020
Madison	-94,522	-0.5	-244	-905	-1536	0.0019

Table 12. Results of the Community/Multifamily scenario; 185,000 ft² of housing.

RESIDENTIAL

The results for the residential scenario (4-ton) are given for each climate in Table 13. Results for this scenario are based on averages of statewide data, so climate is not varied. Instead, results for the residential scenario are given based on the heating fuel used in the conventional case: housing in Wisconsin can often be heated by either natural gas, propane, or electric resistance heat. Additionally, the economic results are given for both horizontal and vertical GHXs, this choice of configuration has a significant effect on installation cost as discussed earlier.

The annual operating cost savings is approximately \$0.11/ft² versus the natural gas conventional case. For a geothermal system with a horizontal GHX this leads to an ROR of 9% (24-year payback); for a vertical GHX it results in an ROR of 7% (32-year payback). Both compare favorably to current mortgage rates, though potentially not as rates increase. Carbon dioxide emissions were similar versus the natural gas case. Mercury emissions decreased and all other emissions increased significantly.

In homes that are heated by propane, geothermal systems have a more significant impact on both economics and emissions. The annual operating savings versus the propane case is \$0.40/ft², yielding a 19% ROR for horizontal systems and a 15% ROR for vertical systems (with simple paybacks of only 7 and 9 years, respectively). Emissions impacts are similar to those for natural gas, except that CO₂ emissions now decrease significantly, by 0.8 lbs/ft² annually.

In homes that use electric resistance heating rather than a furnace, the economic and emissions savings increase further. Annual operating cost savings increase to \$0.79/ft², yielding an ROR of 31% for horizontal systems and 24% for vertical systems (with simple paybacks of only 4 and 5 years, respectively). Dramatic emissions savings are possible with a switch from electric resistance heat to geothermal; annual CO₂ savings are 11.8 lbs/ft², and savings for PM₁₀, SO₂, and NO_x are an order of magnitude higher per ft² than for any of the other building types.

Annual Energy Savings

Available Fuel	Electricity		Demand		Fuel	
	kWh	kWh/ft ²	kW	W/ft ²	therms	therms/ft ²
Natural Gas	-6,934	-2.34	-2.4	-0.81	1,033	0.35
Propane	-6,934	-2.34	-2.4	-0.81	1,033	0.35
Electric only	20,529	6.94	7.0	2.36	---	---

Economics

		Incremental Install. Cost	Oper. Cost Savings	Oper. Cost Savings	Simple Payback	Rate of Return	Simpl. After Tax ROR
		\$	\$	\$/ft ²	years	%	%
Horizontal	Natural Gas	8,200	340	0.11	24.1	8.8	---
	Propane	8,200	1,166	0.39	7.0	19.1	---
	Electric only	8,200	2,328	0.79	3.5	30.9	---
Vertical	Natural Gas	10,800	340	0.11	31.7	7.2	---
	Propane	10,800	1,166	0.39	9.3	15.3	---
	Electric only	10,800	2,328	0.79	4.6	24.1	---

Annual Emissions Savings

	CO ₂ lbs	CO ₂ lbs/ft ²	PM ₁₀ lbs	NO _x lbs	SO _x lbs	Mercury lbs
Natural Gas	359	0.1	-3	-10	-19	0.000026
Propane	2,323	0.8	-3	-5	-19	0.000003
Electric only	34,900	11.8	9	59	56	0.000000

Table 13. Results of the Residential scenario; 4-ton system.

These results suggest that the economic and emission impacts are only weakly dependent on climate. It is likely that cost and emissions sensitivities will significantly outweigh those climatic differences, so the sensitivities below are shown only for the Madison climate (closer to the population-weighted center of the state than the other two climates).

EMISSIONS SENSITIVITY

The emissions results of this study are heavily dependent on the ratio of emission factors between electricity and natural gas. The emissions factors for burning natural gas are not likely to change significantly, but the emissions factors for electricity could change significantly if Wisconsin's mix of electricity generation were to change. One potential driver for this change is the enactment of renewable portfolio standards (RPSs). An existing RPS in Wisconsin mandates 10% of electricity must be renewable by 2015; other states on the grid mandate 25% by 2025. Federal mandates currently being

considered often target 25% renewable electricity. By comparison, currently, 3.6% of the electricity sold in Wisconsin is renewable.

Short of doing a full model of changes to the grid and its generating portfolio, we made certain assumptions in order to estimate the effect of RPSs on the marginal emissions of building systems. It is certainly a stretch to say that marginal emissions are reduced by the percentage change in renewable production. A large portion of the renewables will likely be used as baseload power. However, due to transmission constraints, a significant portion may also be marginal. This could be compounded by the fact that geothermal systems have highest demand during times when solar (summer; see Figure 6) and to a lesser extent wind (in the winter) are at their peak.

Here, this sensitivity analysis makes the gross assumption that half of the effects of added renewable production could be marginal (*note that this may be a fairly optimistic assumption*). For example, we assume that a 25% renewable portfolio yields an electric emissions reduction of 10.7% ($[25\% - 3.6\%]/2$). The following sensitivity plots examine the effects of geothermal systems assuming 10% and 25% RPSs. An additional sensitivity analysis considers the case of a building with significant customer-sited renewable electric production, in which half of the electricity required for the geothermal system is met by a renewable technology like wind or solar photovoltaics.

The sensitivity of CO₂ to these different scenarios is demonstrated in Figure 4. The residential and community scenarios are most sensitive to renewable levels because a larger portion of their energy savings comes from natural gas savings. In fact, these scenarios move from having a CO₂ penalty—or very little savings—to yielding significant CO₂ savings. Conversely, in the office scenario, a large portion of the energy savings comes from reduced electricity from air conditioning, therefore the CO₂ savings actually decreases as more renewables come online. The school scenarios are somewhere between these two extremes.

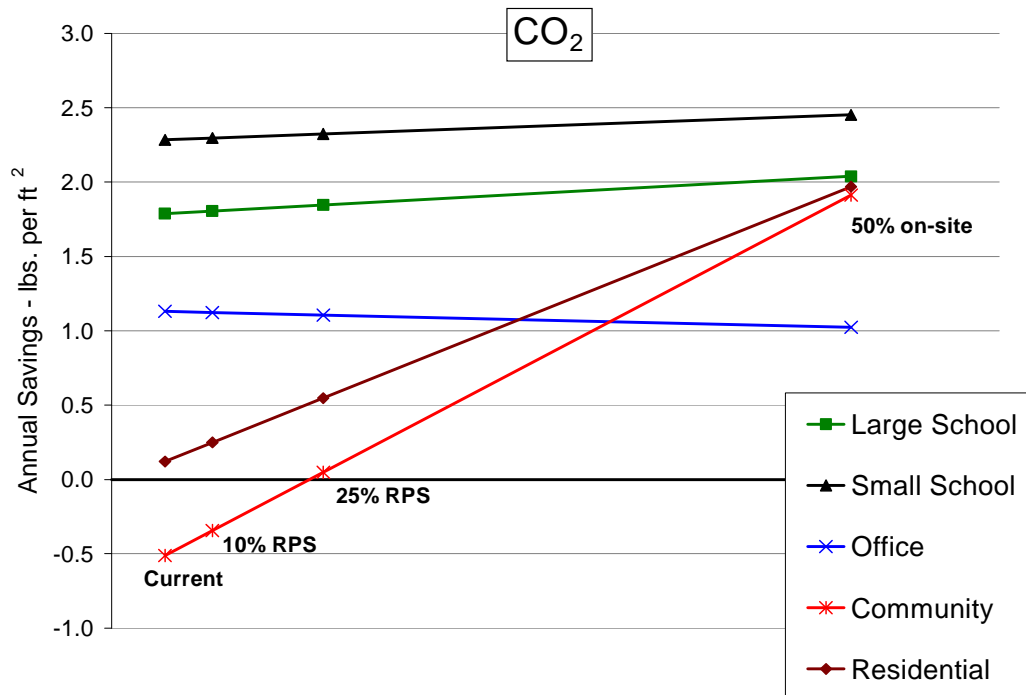


Figure 4. Sensitivity of CO₂ emissions savings (in lbs. per ft²) to various renewable electricity scenarios.

The other emissions sensitivities exhibit similar trends as shown in Figure 5. For PM₁₀, NO_x, and SO₂, the residential and community scenarios approach positive savings as renewables approach 50% of the marginal load; a difficult level to reach.

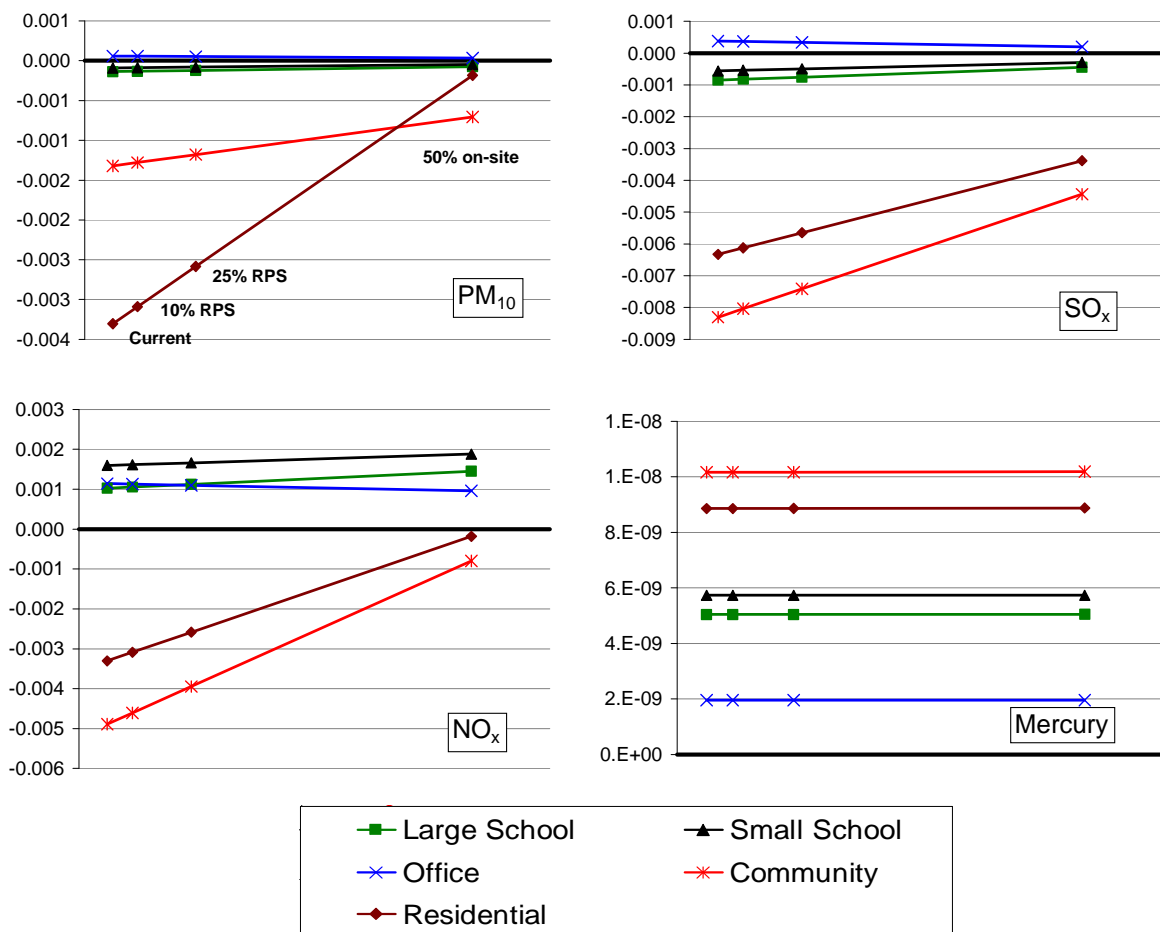


Figure 5. Sensitivity of other emissions savings (in lbs. per ft²) to various renewable electricity scenarios.

INCENTIVE SENSITIVITY

There are a few programs under both the federal renewable tax credits and the state's Focus on Energy program that offer incentives for installing geothermal heat pump systems. The base cases for each scenario did not include these, as they tend to change from year to year (and it was useful from a policy planning perspective to look at the emissions and economics without incentives). This section will explore the effects of the existing incentives:

Focus on Energy: \$250 for the residential and community scenarios (per house); \$150/ton for the office and schools scenarios.

Federal Tax Credit: 10% credit for the installed system cost for the office and community/multifamily scenarios (consistent with a central operator or landlord in multifamily situation), 30% credit for the installed system for the residential scenario.

The current tax and incentive offerings make geothermal systems extremely cost effective in the office and residential (here assuming horizontal installation) scenarios where Focus on Energy offers a

significant incentive and the federal government offers a 10% tax credit (see Table 14). Rate of return goes from 14% up to 43% in the office, and from 8% up to 35% for residential. In both office and residential scenarios, payback goes to just 4 years!

In the community scenario, the 10% federal tax credits modestly increase the ROR to 13%. Payback becomes just 12 years. The school scenarios see only a slight improvement with incentives, because they are currently not eligible for federal tax incentives, as they do not pay income taxes.

Base Case

	Incremental Install. Cost \$	Oper. Cost Savings \$	Oper. Cost Savings \$/ft ²	Simple Payback years	Rate of Return %	Simpl. After Tax ROR %
Large School	1,170,000	112,066	0.29	10.4	15.5	---
Small School	198,375	17,913	0.26	11.1	15.2	---
Office	206,310	14,155	0.21	14.8	12.8	13.7
Community/Multifamily	555,000	30,101	0.16	18.4	10.1	---
Residential (Horizontal)	8,200	340	0.11	24.1	7.8	---

With State/Federal Incentives

	Incremental Install. Cost \$	Oper. Cost Savings \$	Oper. Cost Savings \$/ft ²	Simple Payback years	Rate of Return %	Simpl. After Tax ROR %
Large School	1,053,000	112,066	0.29	9.4	16.8	---
Small School	181,125	17,913	0.26	10.1	16.3	---
Office	59,202	14,155	0.21	4.2	31.4	43.0
Community/Multifamily	363,255	30,101	0.16	12.1	13.2	---
Residential (Horizontal)	1,272	340	0.11	3.7	35.0	---

Table 14. Sensitivity of the results to inclusion of both Federal and State (Focus on Energy) energy incentives and tax credits.

COST SENSITIVITY

It is helpful to demonstrate the impact of fuel and installation costs on the economic results since these costs vary over time and by specific project. For this sensitivity analysis we input higher and lower values for gas, electricity, and installation costs to investigate how different the result would be at the 'boundaries' of each of these variables. These boundaries should encompass the majority of actual project scenarios.

Residential Sensitivity

The residential scenario (with horizontal GHX) includes a significant shift from gas heating to electric heat pump heating, so the relative prices of gas and electricity have a very large effect on the cost effectiveness of geothermal in this scenario (see Table 15). With a low electric rate (\$0.08/kWh) or a high gas rate (\$1.30/therm), which could both be common depending upon time/place, a geothermal system begins to look much more attractive. The low electric rate case has an 11% ROR (15-year payback) and the high gas rate case has a 13% ROR (13-year payback). If gas prices continue to decline as they have been, however, the economics look much worse: a 5% ROR with \$0.70/therm.

Installation costs for geothermal were somewhat bi-modal—though the median cost was \$2100/ton, there were several projects in the survey priced closer to \$1100/ton. At this low cost, the ROR becomes 14% (with a 13-year payback). There were not many typical projects with a horizontal GHX that came in significantly higher than the median, so the higher cost sensitivity had a much smaller effect (there are many ‘luxury’ home projects that come in much higher per ton; these generally include radiant floor heat, larger equipment capacities, more expensive controls, etc.).

	Incremental Install. Cost \$	Oper. Cost Savings \$	Oper. Cost Savings \$/ft ²	Simple Payback years	Rate of Return %	Simpl. After Tax ROR %
Base Case	8,200	340	0.11	24.1	7.8	---
Low gas price (\$0.70/therm)	8,200	30	0.01	271.1	4.6	---
High gas price (\$1.30/therm)	8,200	650	0.22	12.6	12.7	---
Low elec. price (\$0.08/kWh)	8,200	548	0.19	15.1	11.2	---
High elec. price (\$0.125/kWh)	8,200	236	0.08	34.7	7.6	---
Low install. cost (\$1080/ton)	4,320	340	0.11	12.7	14.2	---
High install. cost (\$2500/ton)	10,000	340	0.11	29.4	7.6	---

Table 15. Sensitivity of Residential scenario results to changes in fuel costs and installation cost difference.

Office/School Sensitivities

Commercial and institutional buildings like schools and offices are not quite as susceptible to the relative prices of gas and electricity because they have relatively smaller heating loads. In fact electric rates do not vary significantly enough in these sectors to have a large impact on the results, so those sensitivities are not included here.

Gas price does have a significant impact on the small school results (see Table 16); the ROR varies between 14% and 18% (payback goes from 14 years to 9) as the gas price varies from \$0.65/therm to \$1.20/therm. This effect is much smaller in the office scenario, where heating is less of a factor.

The economics of these scenarios are most sensitive to variance in installation cost. This is primarily because the installation cost difference between geothermal and conventional systems varies so much in commercial buildings depending on the project. We found cost differences as low as \$2.2/ft² and result in RORs of 18% and 21% (9- and 7-year paybacks) in the office and school scenarios, respectively. We also saw cost differences as high as \$5.5/ft², which drove the ROR down to 11% in both scenarios—still potentially cost effective though.

Office Scenario

	Incremental Install. Cost \$	Oper. Cost Savings \$	Oper. Cost Savings \$/ft ²	Simple Payback years	Rate of Return %	Simpl. After Tax ROR %
Base Case	206,310	14,155	0.21	14.8	12.8	13.7
Low gas price (\$0.65/therm)	206,310	12,942	0.19	15.9	12.2	13.3
High gas price (\$1.20/therm)	206,310	15,843	0.23	13.0	13.6	14.3
Low install. cost (\$2.2/ft ²)	131,560	14,155	0.21	9.3	17.7	17.8
High install. cost (\$5.5/ft ²)	328,900	14,155	0.21	23.2	9.1	10.5

Small School Scenario

	Incremental Install. Cost \$	Oper. Cost Savings \$	Oper. Cost Savings \$/ft ²	Simple Payback years	Rate of Return %	Simpl. After Tax ROR %
Base Case	198,375	17,913	0.26	11.1	15.2	---
Low gas price (\$0.65/therm)	198,375	14,344	0.21	13.8	13.5	---
High gas price (\$1.20/therm)	198,375	22,879	0.33	8.7	17.5	---
Low install. cost (\$2.2/ft ²)	126,500	17,913	0.26	7.1	21.1	---
High install. cost (\$5.5/ft ²)	316,250	17913	0.26	17.7	10.8	---

Table 16. Sensitivity of Office and Small School scenarios results to changes in fuel costs and installation cost difference.

OTHER CONSIDERATIONS

The results of this report focus on the economic and environmental impacts of choosing a geothermal system for a variety of building types. Though economic and environmental impacts are primary, there are a few other issues to consider. For example, in some applications geothermal heat pump systems allow for greater occupant comfort by making zoning of individual rooms and occupant spaces more convenient. This advantage should be discussed with the mechanical/controls designer in any given building project.

Geothermal systems also create more stable utility bills by switching the fuel for heating of the space from gas to electricity. Historically electricity prices have seen much less volatility than natural gas prices.

Other 'intangible' effects of geothermal systems include differences in noise levels (which depends heavily on the location of the heat pump), aesthetic benefits from less equipment on the rooftop, and challenges associated with operating a system that may be completely new to an owner (or at least unique in their portfolio).

From a utility perspective, geothermal systems have an additional advantage as an effective demand reduction technology. Growing demand can create the need for additional utility infrastructure, so utilities may be concerned as much with demand reduction as with energy consumption reduction. Because geothermal systems provide cooling, they naturally can have a large impact on summer peak demand. Figure 6 demonstrates the average load shapes for geothermal systems in July, for residential

and office building types. Note that these systems peak in the afternoon between 1:00 and 4:00 pm, coincident with peak demand in Wisconsin.

All of the costs, benefits, and societal impacts should be considered when making any systems decision.

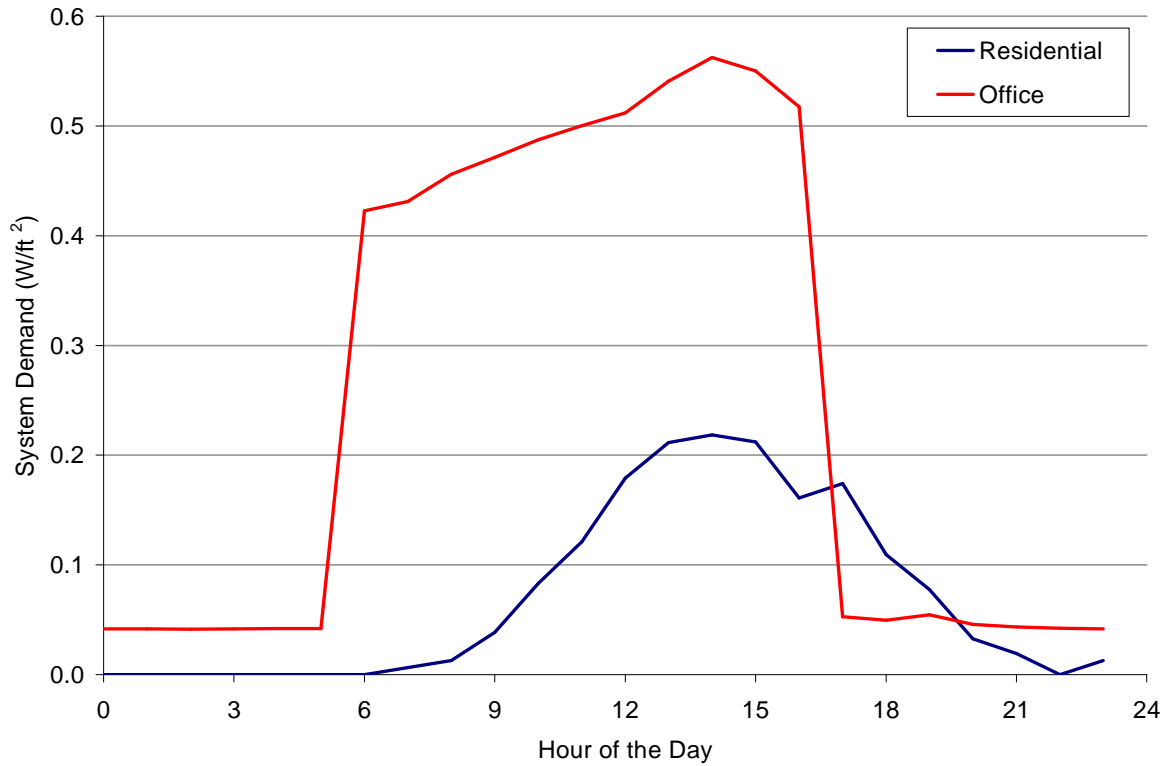


Figure 6. Average July load shape for geothermal heat pump systems in two different building types.

CONCLUSIONS

ECONOMIC CONCLUSIONS

Rate of return. Of the two economic metrics used in this study, ROR is the only one that accounts for all the impacts of system selection (first costs and energy costs, plus replacement/salvage, taxes, depreciation, etc.). We therefore recommended it as a superior metric for this study. Based on ROR, geothermal heat pump systems appear to be cost effective across most scenarios in Wisconsin. Rate of return was greater than 10% for all scenarios except residential (for the office scenario it was generally 14% and the schools scenario approached 17%). For the residential scenario ROR was 9% if a horizontal GHX was possible and 8% for a vertical GHX. All of these RORs are greater than the cost of capital (mortgages for residences and businesses, bonds for schools) generally seen in Wisconsin—thus the conclusion that geothermal is generally cost effective in Wisconsin. The results from the office scenario show that the tax effects on private corporations generally increase the ROR by ~1 percentage point due to the favorable depreciation terms of geothermal systems.

Payback. Though ROR has advantages for assessing the cost benefit of heating and cooling systems, simple payback is still used as a common metric in deciding on systems for all types of buildings. It is helpful to consider the simple payback results to understand how geothermal systems advance in the market. In the school scenarios, the payback was 9-10 years, with a shorter payback for the large school scenario due to economies of scale in drilling. In the office scenario payback increased to 14-15 years—though payback is an especially poor metric for private corporations due to tax effects. In the residential and community scenarios, payback varied from 19 – 24 years (again with a shorter payback in the community scenario due to economies of scale).

Climate. The economics of geothermal systems were not heavily dependent on the climate within Wisconsin that was modeled. For example, the ROR of the office scenario only changed from 13.7% to 13.9% in moving from Madison to Green Bay. Similarly, the small school scenario changed from 15.2% to 16.3% for the same two locations.

Incentives. Incentives currently available at the federal and state (through Focus on Energy) levels improve the economics of all geothermal systems. In the community scenario, the federal tax credits increase the ROR to 13% (from 10%); this decreases the payback to 12 years (from 18). The school scenarios see only a modest improvement with incentives, because they are currently not eligible for federal tax incentives. The office scenario becomes extremely cost effective; ROR goes from 14% up to 43%. Similarly, the residential ROR goes from 8% up to 35%. In both these cases, payback goes to just 4 years.

Cost Impacts. Costs also have a large impact on the results. In the residential scenario, as natural gas costs vary from \$0.70/therm to \$1.30/therm the ROR varies from 5% to 13%. Geothermal installation costs for typical horizontal systems did not tend to vary significantly above the median, but on the low end (\$1100/ton) lower installation costs improved the ROR to 14% (a 12-year payback). In the office and schools scenarios the fuel prices had a smaller impact than in the residential scenario, but variability in installation costs had a much larger impact. We found cost differences as low as \$2.2/ft² for vertical commercial systems, resulting in RORs of 18% and 21% (9 and 7-year paybacks) in the office and school

scenarios, respectively. We also saw cost differences as high as \$5.5/ft², which drove the ROR down to 11% in both scenarios (still potentially cost effective).

EMISSIONS

With increased focus on the societal and environmental impacts of energy use, it was important to consider the impact of geothermal heat pump energy use on the environment¹². Carbon dioxide emissions have been subject to the most scrutiny recently, due to their role as a greenhouse gas. In fact, it is possible that in the future CO₂ would be a part of the economic analysis in studies like this, as the United States considers options for controlling CO₂ emissions such as trading them as a commodity.

In the office and schools scenarios, geothermal heat pump systems decreased CO₂ emissions by 6 – 15%, consistently reducing emissions of the greenhouse gas in all cases. In the residential and community/multifamily scenarios, CO₂ generally remained constant or increased slightly with inclusion of a geothermal heat pump system. Whether CO₂ remains constant or increases seems to depend on the relative heating and cooling load of a home; the poorer the insulation, the higher the heating load and the more likely CO₂ will increase with a switch to geothermal. The more cooling that's required in the home (a home with high solar gain, for instance), the more likely CO₂ is to remain constant with the addition of geothermal. However, in the case where the conventional system uses electric heat instead of natural gas heat, CO₂ emissions are reduced by 40%.

Emissions of other pollutants follow differing trends, based upon their relative emission rates when shifting from gas heat to the electrically driven heat pumps. Mercury emissions are always decreased with adoption of geothermal heat pump systems; mercury emission rates at power plants have been reduced below those of natural gas combustion on a per unit basis. Particulate matter (PM₁₀) and SO₂ are emitted at higher rates in the production of electricity and follow the opposite trend. Both pollutants always increase with adoption of geothermal in all scenarios except in the office scenario and in electrically-heated residences. Nitrous oxides (NO_x) decrease with geothermal in all office and school scenarios (buildings with substantial cooling loads) but increase with geothermal in residential and community scenarios, which are dominated by heating (again with the exception being electrically heated residences).

We also considered the sensitivity of emissions impacts to renewable portfolio standards. As the renewable share of marginal electricity generation increases, the impact of residential geothermal systems improves considerably for all pollutants studied. With enough renewable capacity, geothermal becomes a net-saver of all emissions. For school and office building types, increases in renewable generation had much less effect on emission impacts.

¹² There are other non-energy environmental effects, such as the impact of creating the HVAC equipment itself, the effect of the GHX on ground temperatures, water consumption of the different systems, etc. This study focuses on energy usage as it is assumed to have greater impact on the environment in Wisconsin than these other effects.

OTHER CONCLUSIONS

Finally, it is important to remember that results of this study are dependent on many variables that can be very specific to a given project. If this study is used to assist in decision-making for any specific project or group of projects the results should be considered only in light of the assumptions used here. Additionally, there are other considerations, such as occupant comfort, which cannot be captured by an economic or environmental analysis.

This analysis should be helpful, though, in determining the general applicability of geothermal systems to typical projects, informing the treatment of geothermal in efficiency and emissions policies, and identifying the effects of key variables in both of these areas. The sensitivities modeled here can be used to determine how the results should be considered as emissions factors and costs change in the future. Additionally, now that geothermal systems are becoming more prevalent in Wisconsin it would be helpful to obtain performance data from actual buildings to benchmark the results of the models used here. Isolation of the effects of geothermal and other efficiency measures would be a challenge; retrofits or 'typical' building geometries may mitigate the problem. Future work should also study models or actual buildings that use variations on geothermal that are only now emerging, such as central systems, hybrid systems for cooling-dominated buildings, and direct exchange systems.

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