

Case Study: Geothermal Viability Compared to Four Traditional HVAC Systems

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VYRON

Geothermal Office Building Analysis

Presented by Vyron

Executive Summary

This whitepaper presents a technical and financial analysis of HVAC replacement options for a mid-sized office building, culminating in the selection of a geothermal system. The study begins by outlining the owners' need to replace the existing HVAC system and evaluates four potential design alternatives: a conventional Rooftop Unit (RTU) system with gas heat and direct expansion (DX) cooling, a hydronic chiller-boiler system with 4-pipe fan coils, a geothermal system with a vertical glycol field paired with water-to-water heat pumps, and a Variable Refrigerant Flow (VRF) system using air-source heat pumps with zoned indoor units. Energy modeling and life-cycle cost analysis were performed to assess energy consumption, utility costs, equipment lifespan, maintenance needs, and the resulting comfort and controllability of each system. Modeled energy use was also compared against historical utility bills, providing a real-world calibration point and ensuring that results reflected the building's actual operating conditions. While the geothermal system had a longer payback period than some conventional options, its superior long-term efficiency, stability, and sustainability ultimately made it the preferred choice. Post-installation data further validated the analysis, confirming the system's projected performance and financial viability.

Introduction

The project site is a single-story 13,743 sq ft commercial building in Waukesha, Wisconsin, consisting of approximately 2,380 sq ft of warehouse and 10,234 sq ft of office area. Based on the 2021 NFPA 101 Life Safety Code, the design occupancy was calculated at 154 people. The building is unoccupied during nighttime hours, offering potential for HVAC scheduling strategies to reduce off-hour energy consumption. Utility rates used for the analysis were \$0.16 per kilowatt-hour for electricity and \$0.87 per therm for natural gas, based on local utility averages at the time of modeling. The existing (VRF) system—installed roughly 8 years prior—had begun to show declining reliability, with frequent service calls and rising maintenance costs. These challenges underscored the need for a replacement system that could deliver reliable comfort, lower lifecycle costs, and improved energy performance. In addition to cost savings, the building owner identified several key objectives for the new system:

- Reduce energy consumption and avoid dependence on fossil fuels
- Maintain or improve indoor air quality (IAQ) and occupant comfort
- Enable multi-zone controllability
- Minimize maintenance requirements
- Take advantage of available government incentive programs
- Extend system lifecycle

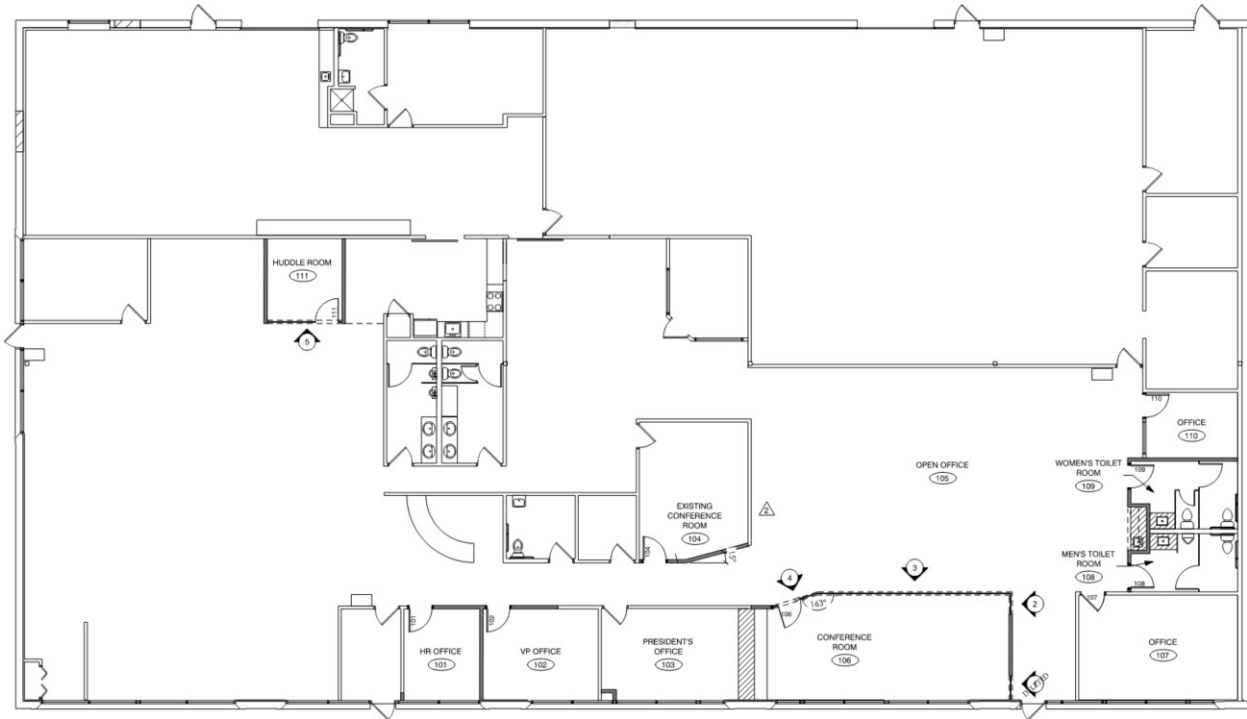


FIGURE 1: BUILDING FLOOR PLAN

System Comparison

System Definitions

Chiller-boiler - A hydronic system with gas-fired boiler for heating and a chiller for cooling. The conditioned water is circulated through a 4-pipe distribution system to (13) fan coil units (FCUs), each serving a dedicated zone. The system allows simultaneous heating and cooling to different spaces, enhancing thermal control flexibility. An energy recovery ventilator (ERV) is included to pre-condition supply air, reducing the heating load on the boiler.

Geothermal (GEO) - This system features (2) reversible water to water chillers connected to a vertical bore field—a series of deep holes to cycle nearly-constant-temperature ground water—beneath the parking lot. Heat is either extracted from or rejected to the underground closed-loop glycol-water circuit. The system supplies hot and chilled water to (13) 4-pipe fan coil units, offering zone heating and cooling with reduced reliance on fossil fuels. An ERV is included to pre-condition supply air, reducing the heating load of the heat pump.

Variable refrigerant flow (VRF) - A variable refrigerant flow (VRF) system is a type of heat-pump-based system that connects a single outdoor condensing unit to multiple indoor units via refrigerant piping. The proposed design includes (14) indoor units, each serving its own zone. These units can operate independently, allowing simultaneous heating and cooling across different spaces based on specific zone requirements. An ERV is included to pre-condition supply air, reducing the heating load of the system.

Rooftop units (RTU) - A traditional system of rooftop units equipped with gas fired heating and DX cooling. The rooftop units precondition the air to 55 degrees which is distributed via ductwork to

variable-air-volume (VAV) boxes with hot water (HW) or electric resistance reheat. This building's proposed layout utilizes (3) RTUs which serve (13) VAV boxes throughout the building.

TABLE 1. SYSTEM COMPARISON

Criteria	Chiller-Boiler	Geothermal	VRF	RTUs
Initial Cost	Moderate	High	Moderate/high	Low
Fuel Source	Gas/Electric	Electric	Electric	Gas/Electric
Efficiency	Moderate	High	High	Low/moderate
Lifespan	20–25 yrs	25–30 yrs (50+ for bore field)	10–15 yrs	10–15 yrs
Maintenance	Low/moderate	Low/moderate	Moderate/high	Moderate
Incentives	Low (1-5%)	High (30-55%)	Low (2-10%)	Minimal (0-1%)
Design Complexity	Moderate	High	High	Low

System Components

TABLE 2: SUMMARY OF SYSTEMS

Chiller-Boiler	<ul style="list-style-type: none"> (1) 28-ton chiller (1) Hot water boiler (13) Fan coil units (1) Energy recovery ventilator (1) Direct fired MAU
Geothermal (Proposed Solution)	<ul style="list-style-type: none"> (2) 15-ton reversible water-water chillers (13) Fan coil units (1) Energy recovery ventilator (1) Direct fired MAU
VRF	<ul style="list-style-type: none"> (3) VRF outdoor units (14) Indoor units (1) Energy recovery ventilator (1) Direct fired MAU
RTU/HW	<ul style="list-style-type: none"> (3) Rooftop units with IG furnace, DX cooling, economizer (13) Hot water VAV boxes (1) Hot water boiler (1) Direct fired MAU
RTU/Electric	<ul style="list-style-type: none"> (3) Rooftop units with IG furnace, DX cooling, economizer (13) Electric VAV boxes (1) Direct fired MAU

Incentive Overview

The two most impactful incentives for this installation were the Federal Investment Tax Credit (ITC) and the Wisconsin Focus on Energy rebate. The ITC alone offsets 30–50% of the total geothermal project cost, making it the single largest driver in reducing net installed cost. In contrast, the Focus on Energy incentive typically contributes a smaller portion—roughly 2.5% of project cost—but still provides meaningful support. Beyond these direct incentives, geothermal projects may also benefit from mechanisms such as accelerated depreciation (including bonus depreciation) and the Section 179D commercial building deduction. These provisions can further strengthen project economics; however, they are beyond the scope of this paper.

Federal Investment Tax Credit (ITC – Section 48)

The geothermal system qualified for the Federal Investment Tax Credit (ITC) under Section 48 of the Inflation Reduction Act. This credit provides a 30% base incentive for qualifying commercial geothermal heat pump projects, provided that the installation meets the prevailing wage and apprenticeship requirements established by the IRS. If these labor requirements are not met, the credit drops to 5%, making compliance essential for securing the full benefit. In addition to the base credit, certain projects may qualify for bonus adders. The Domestic Content adder provides an additional 10% credit when at least 50% of the project's steel, iron, and manufactured components are sourced from the United States. A separate Energy Community adder, also worth 10%, applies when the project is located in a designated census tract tied to fossil-fuel industry employment, coal closures, or historically elevated unemployment. When combined, these incentives can substantially reduce the effective cost of geothermal installation. The total combined incentives can accrue up to 50%; however, our application yielded 40% due to our site location disqualifying the project from the Energy Community credit.

Wisconsin Focus on Energy Rebate

In addition to federal tax incentives, the project also received support through the Wisconsin Focus on Energy program, which provides utility-funded rebates for verified efficiency improvements. Unlike ITC, which is based on project cost, Focus on Energy rebates are awarded based on measured or modeled energy savings relative to baseline equipment. For this project, the geothermal system qualified for a rebate of approximately \$16,920, reflecting the expected reduction in annual energy consumption compared to the alternative HVAC configuration, which was the electric VAV RTU system. This rebate further reduced the net installed cost and contributed to the overall economic viability of the geothermal system.

Results

Energy Modeling

The energy modeling was completed using Carrier HAP, evaluating five different HVAC system configurations for the office. To maintain consistency across the alternatives, each system was modeled using standard, industry-typical equipment and features, rather than high-end or specialized options. The following figures summarize the modeled results, beginning with utility cost and energy use comparisons, followed by financial metrics such as payback, life-cycle cost, and return on investment. Together, these results illustrate the relative efficiency and long-term economic performance of each system.

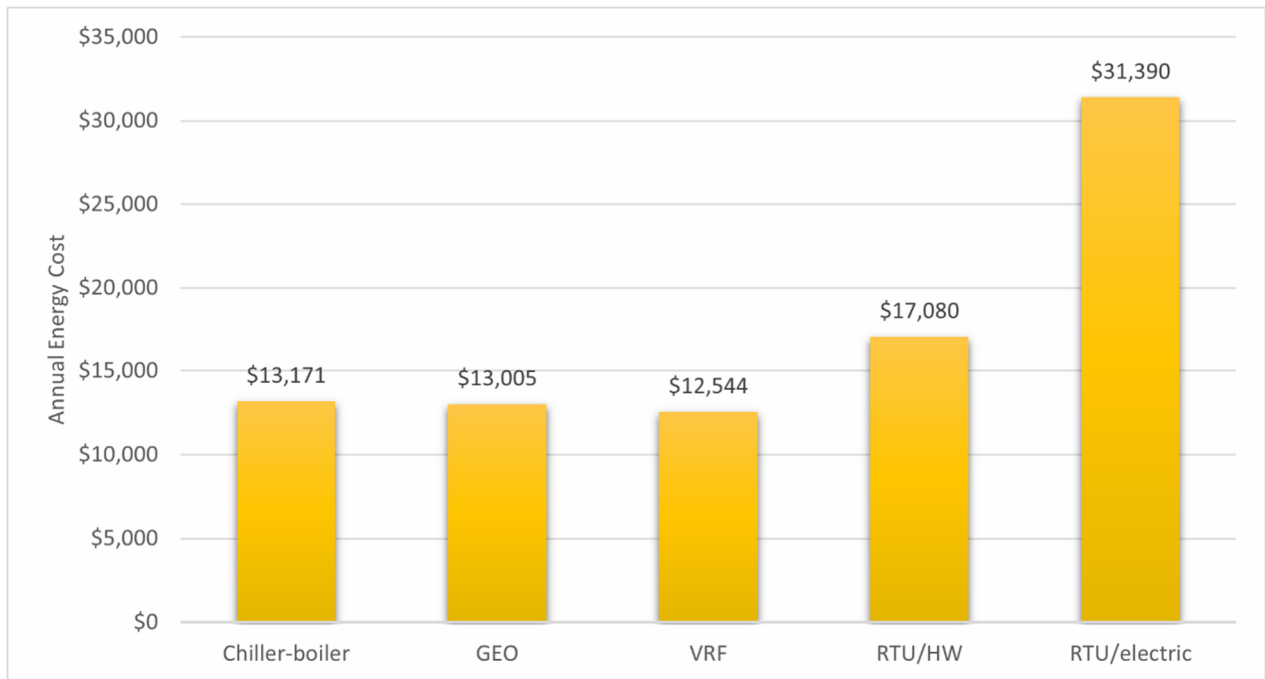


FIGURE 2: TOTAL ANNUAL UTILITY COSTS BY SYSTEM

Figure 2 compares the total annual utility costs for the five HVAC systems analyzed. The rooftop systems with electric reheat show the highest operating cost—more than double that of the VRF, geothermal, and chiller/boiler systems. This significant difference is driven by the inflated cost of electric resistance heating and the lower overall system efficiency compared to heat-pump-based or hydronic systems.

Among all the systems, the VRF system achieved the lowest annual utility cost. This is primarily due to its ability to modulate capacity and recover heat between zones, which minimizes wasted energy and reduces both heating and cooling loads. The geothermal and chiller/boiler systems performed nearly identically, with energy costs only slightly higher than VRF. Their impressive performance is attributed to the high efficiency of water-source heat exchange and the reduced temperature lift required for heating and cooling. The rooftop units with hot-water VAV boxes showed higher utility costs than the more advanced systems but operated at about half the utility cost of the electric VAV configuration. This is because using natural gas for heating is substantially more cost-effective than electric resistance heating, particularly in a heating-dominant climate like Wisconsin.

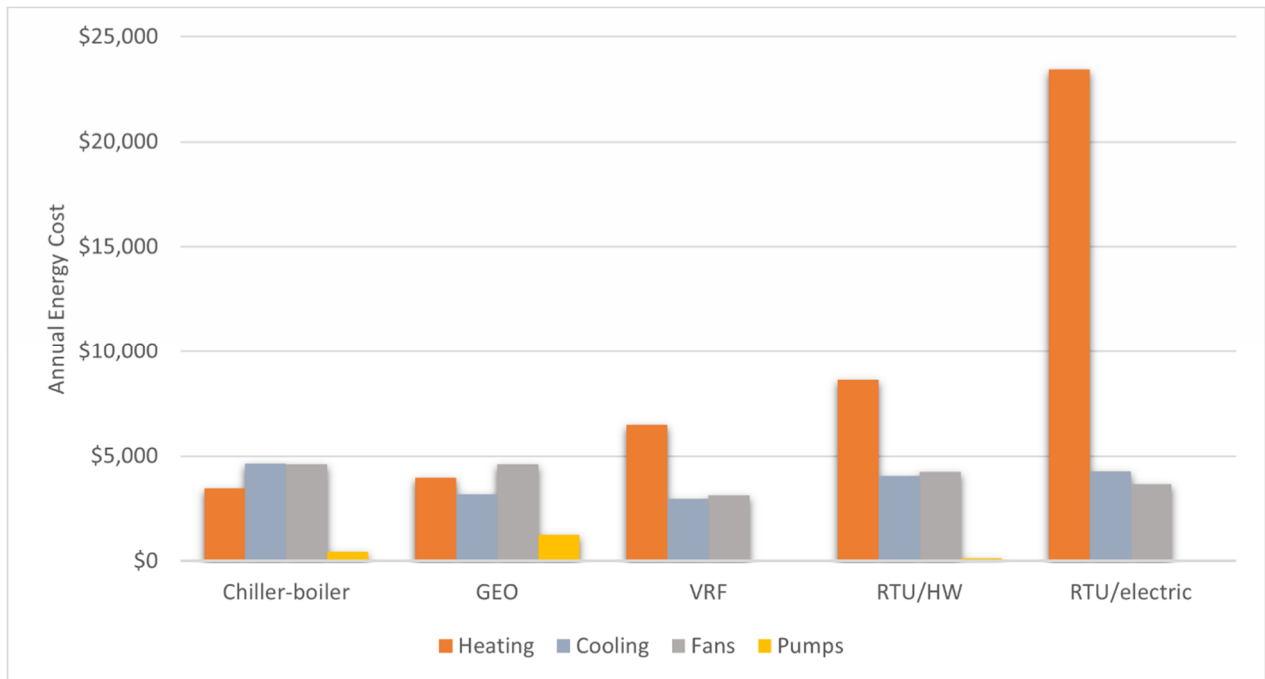


FIGURE 3: ANNUAL UTILITY COSTS BY SYSTEM AND USE

Figure 3 illustrates the total annual energy cost for each HVAC system evaluated separated by heating, cooling, fan, and pump energy use. In Wisconsin’s climate, heating represents the largest portion of energy use, as the state experiences most annual hours with heating demand throughout the year. The results highlight that systems relying on electric resistance heating—specifically the RTU with electric reheat—have a significantly higher annual energy cost compared to all other system types. This disparity stems from the cost differential between electricity and natural gas, which amplifies the operating expense of electric heating under cold-weather conditions.

On a cost-per-energy basis, electricity is substantially more expensive than natural gas in Southeastern Wisconsin. The cost of electricity, assuming 100% conversion efficiency, is approximately \$0.16/kWh or \$0.0469 per kBTU, whereas natural gas costs around \$0.87/therm or \$0.0087 per kBTU. This means that for the same dollar spent, natural gas provides more than five times the usable energy of electricity. As a result, systems relying primarily on electric heating show higher energy costs in this climate compared to heating from natural gas.

The geothermal and hydronic systems yield the lowest annual utility costs, driven largely by the high heating efficiency of water-source heat pumps and boiler-based systems. VRF also performs well, combining strong equipment efficiency with limited reliance on supplemental electric heat during extreme conditions. Fan energy was generally comparable across most systems, except for VRF, which maintains an advantage due to its lower total pressure drop. VRF units typically use more efficient fans, have only one coil in the airstream, and operate with low-resistance MERV 4 filtration. In contrast, the other systems use MERV 10 filters, which provide superior air filtration but cause more resistance to air flow. The other systems also require airflow across both heating and cooling coils, further increasing static pressure. Figure 4 below illustrates how fuel type, system efficiency, and local energy rates

interact to shape each system’s operating cost profile.

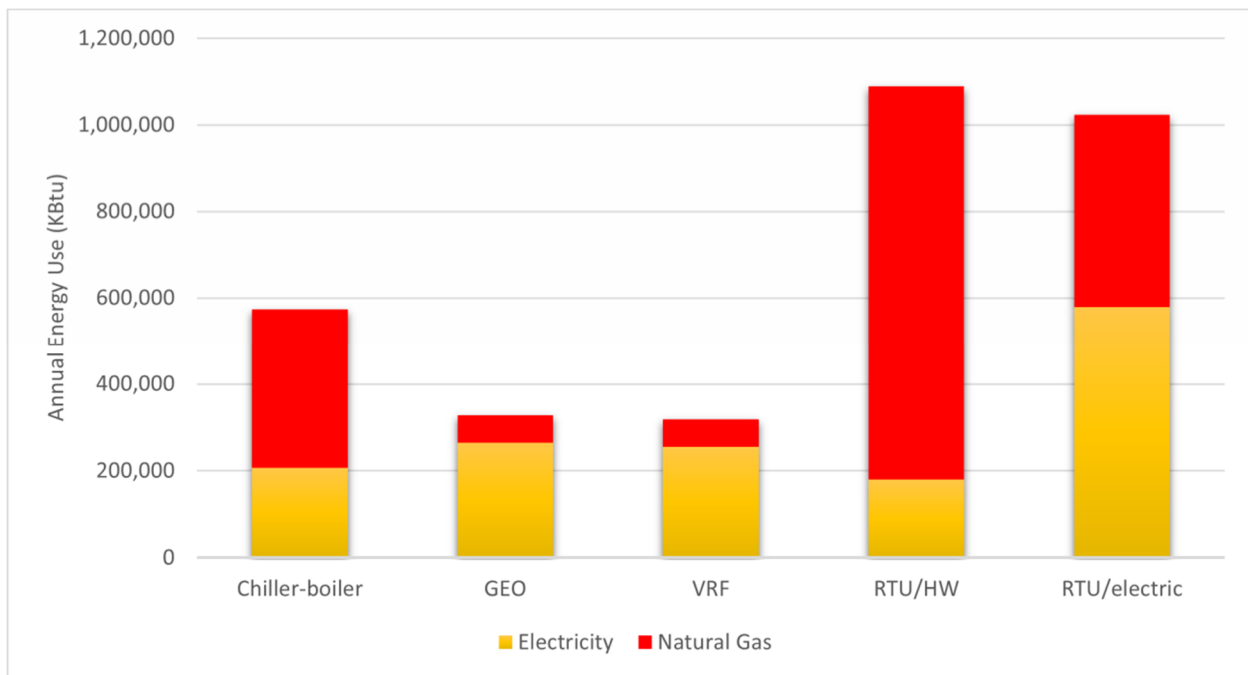


FIGURE 4: TOTAL SITE ENERGY USAGE BY SYSTEM

In contrast, the total site energy consumption shown in Figure 4 provides a broader perspective on system performance. The geothermal and VRF systems again demonstrate nearly identical annual energy use and remain the most energy-efficient of the five alternatives evaluated. The chiller-boiler system, while consuming nearly twice as much total site energy as the geothermal and VRF systems, still results in a comparable utility cost because a significant portion of its energy comes from relatively inexpensive natural gas. The rooftop system with hot-water VAV boxes shows an even larger difference, using almost four times more site energy than the geothermal and VRF systems.

A primary driver of these differences is the heating energy. Systems relying on boilers or gas-fired furnaces inherently consume more total site energy because they create heat through combustion, typically achieving efficiencies of 80–95%. In contrast, heat-pump-based systems—such as VRF and geothermal—do not generate heat; they move heat. With heating coefficients of performance (COPs) commonly ranging from 3.0 to 5.0, heat pumps can deliver three to five units of heat for every unit of electrical energy consumed.

This thermodynamic advantage is especially important in a heating-dominant climate like Wisconsin. It explains why the geothermal and VRF systems maintain such low total energy consumption despite the significant heating loads. Even with colder outdoor temperatures and long heating seasons, these systems achieve substantial efficiency gains simply because heat transfer is far less energy-intensive than heat generation. The result is a dramatic reduction in site energy use, putting geothermal and VRF in a much more advantageous energy performance category than the other system types.

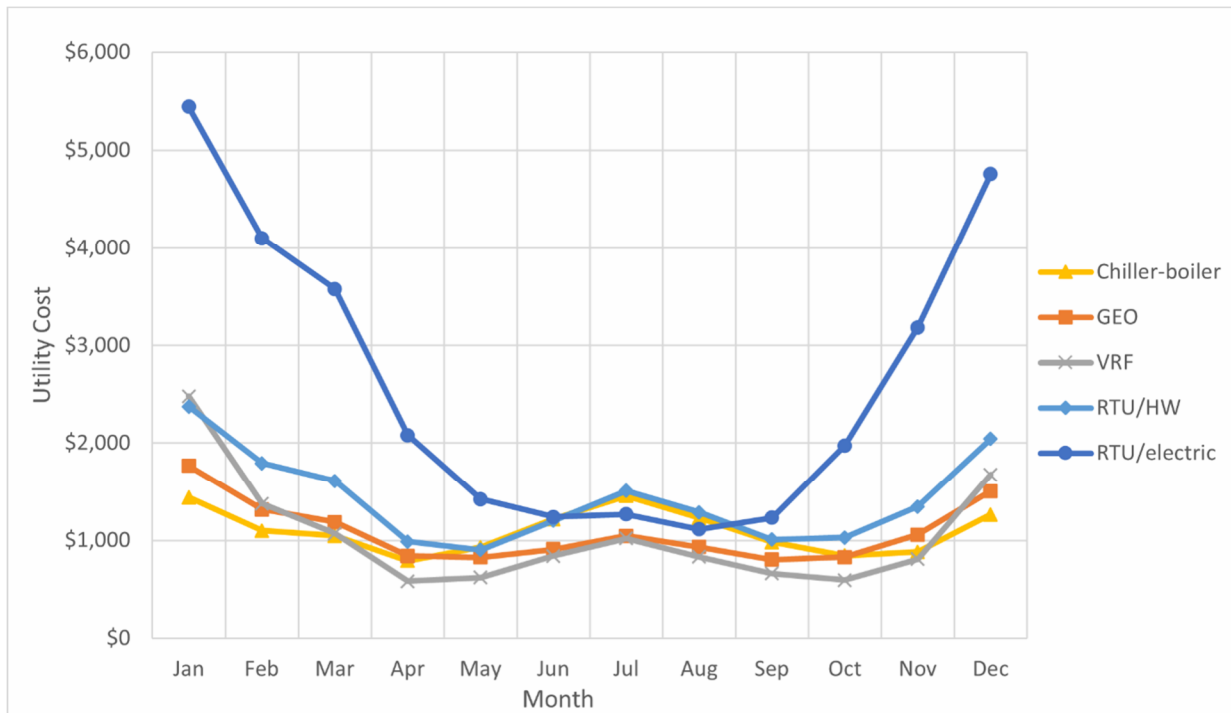


FIGURE 5: MONTHLY UTILITY COSTS BY SYSTEM

The monthly utility cost profile highlights the seasonal variation in energy use and cost throughout the year in Wisconsin’s climate. As expected, utility costs rise sharply during the winter months, when heating demand dominates, and again during the hottest summer months, when cooling loads peak. The shoulder seasons—spring and fall—have significantly lower utility costs due to the reduced need for space conditioning, as outdoor air temperatures remain close to indoor comfort conditions.

Among the systems analyzed, the electric VAV rooftop system consistently demonstrates the highest monthly costs during the winter, driven by the inefficiency and high cost of electric resistance heating. In contrast, the VRF, geothermal, and chiller/boiler systems maintain a more moderate and consistent cost profile across the year, reflecting their higher heating efficiencies and better part-load performance. The geothermal system, in particular, benefits from the stable ground temperature, which limits seasonal efficiency fluctuations. This is why the utility cost has less variation in the geothermal curve versus the VRF. Another trend can be seen in the chiller boiler system. Since it uses gas heating in the winter the cost is relatively low during the winter months and shoulder season, while in the summer months the cost jumps higher, again due to the cost disparity between gas and electricity. Overall, all the systems follow a similar annual cost trend except for RTUs with electric VAVs with the high peaks in the winter.

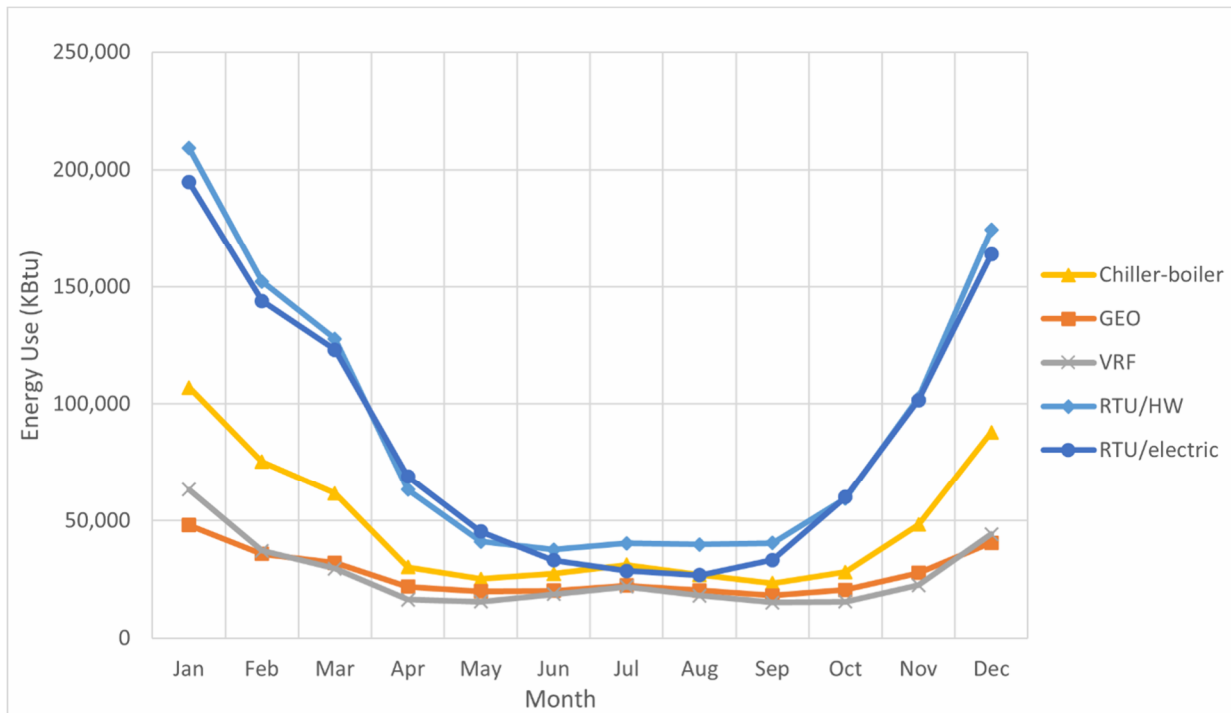


FIGURE 6: MONTHLY ENERGY USE BY SYSTEM

Another interesting effect is observed in the monthly energy-use profiles shown in Figure 5. The rooftop units with hot-water VAV reheat and those with electric VAV reheat exhibit nearly identical seasonal patterns, following the same winter peak and summer trough. This similarity arises because both systems share the same fundamental air-based rooftop configuration, ventilation loads, and control strategies, with the only major difference being the energy source used for reheating. As a result, their part-load behavior and overall heating and cooling profiles are nearly indistinguishable.

The VRF and geothermal systems also show closely aligned monthly profiles, characterized by substantially lower peaks in both the heating and cooling seasons. This shows the advantage of heat-pump-based systems, which are able to modulate capacity efficiently under part-load conditions and avoid the high winter energy demand associated with combustion-based heating. Geothermal exhibits even smoother performance because it exchanges heat with the ground, where temperatures are far more stable throughout the year, reducing the impact of outdoor temperature swings. VRF, on the other hand, benefits from heat recovery capability, allowing it to redistribute heat internally between zones rather than rejecting or absorbing it from the outdoors, further flattening its seasonal energy curve.

The chiller/boiler system follows the same general seasonal pattern but shows noticeably higher winter energy use compared to VRF and geothermal. This increase is driven by the lower heating efficiency of boilers, which must generate heat through combustion rather than transfer it using heat pump technology. As a result, the system requires more total energy input to meet the same winter heating load. Together, these monthly profiles highlight how system type, heat-pump efficiency, and heat-source stability shape the seasonal energy performance of each alternative.

Financial Analysis

Figure 7 presents the total first costs for each HVAC system. As shown, the hydronic-based systems are the most expensive to install. This higher initial cost is primarily due to the additional infrastructure and equipment requirements, including pumps, piping networks, fan coil units, and more complex central plant components. The geothermal system adds further cost due to the need for a ground heat exchange source, such as a pond loop or vertical bore field. In this analysis, we used a vertical bore field because this was the groundwater circulation system selected by the owner. Despite the apparent high first cost of geothermal systems, available federal incentives substantially reduce this cost, making geothermal competitive with VRF and chiller/boiler systems.

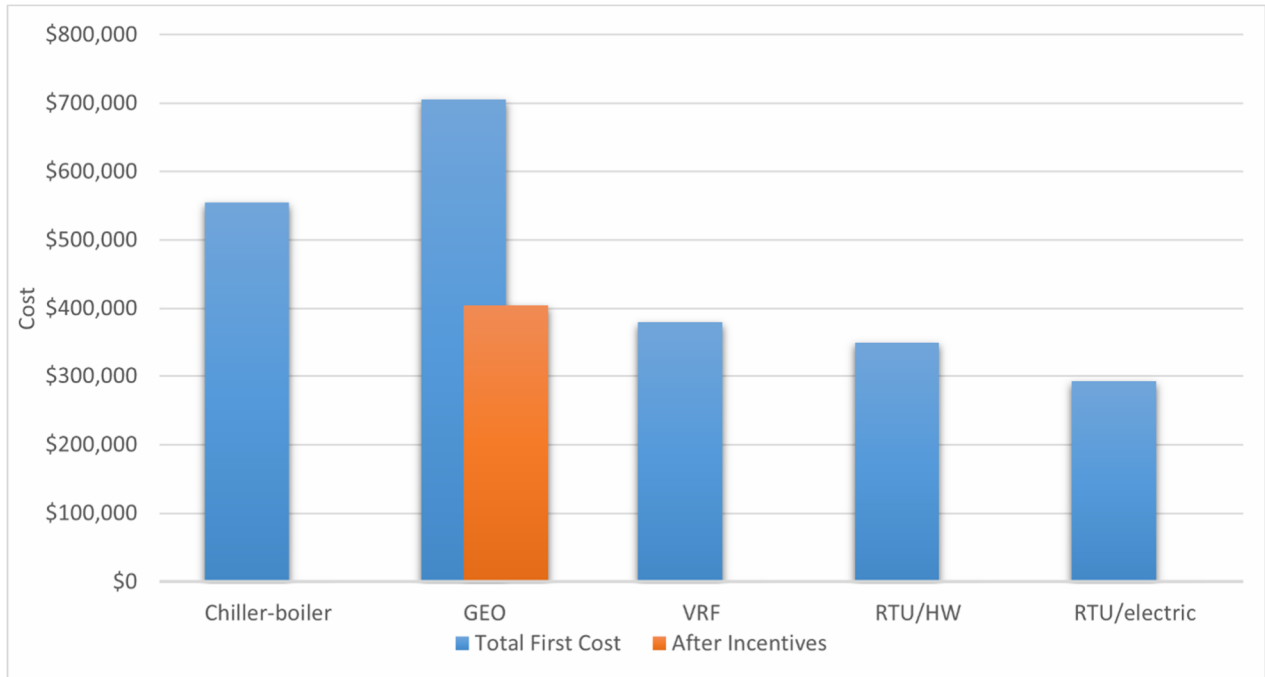


FIGURE 7: TOTAL FIRST COST OF EACH SYSTEM

Figure 7 highlights how dramatically incentives can improve the financial outlook of a geothermal installation. In this case study, the combination of federal tax credits and the Focus on Energy rebate reduced the geothermal system’s installed cost by roughly 40%, immediately narrowing the gap between geothermal and other system types. When additional benefits such as accelerated depreciation or Section 179D deductions are factored in, the effective cost can drop even further, in some cases exceeding a 50% reduction. These incentives transform geothermal from one of the highest first-cost options into a financially competitive alternative, making it a viable choice for Wisconsin projects where upfront cost is often a major barrier.

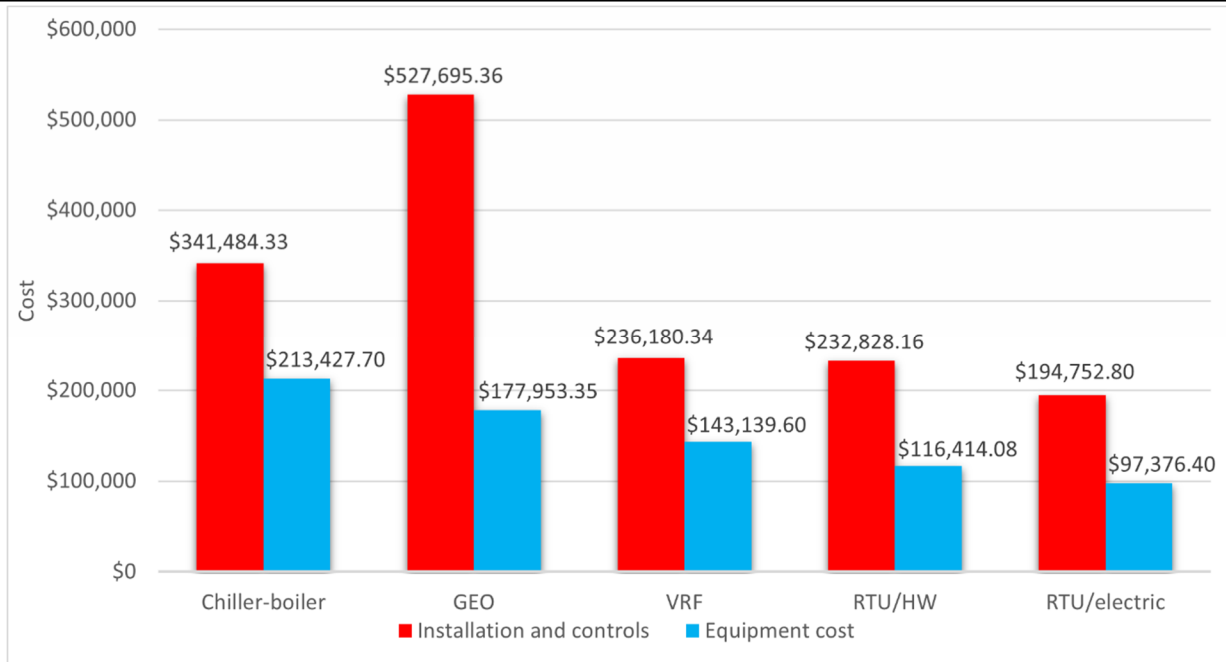


FIGURE 8: INSTALLATION AND CONTROLS VS EQUIPMENT COSTS

Figure 8 presents the total first costs for each HVAC system, divided into equipment and installation components. The data reveals a clear cost distinction between hydronic-based and air-based systems. The Chiller/Boiler and Geothermal configurations have the highest equipment costs, largely due to the added capital associated with pumps, piping, heat exchangers, and hydronic distribution components. Among all the systems, the Geothermal option shows the greatest installation expense because of the bore field construction required to serve as the thermal exchange source. This field of work significantly increases labor and installation hours. As a result, hydronic systems in general carry both higher equipment and higher installation costs compared to their air-based counterparts.

In contrast, the RTU systems—both hot-water and electric reheat—show substantially lower installation costs due to their factory-packaged nature and minimal field labor requirements. These units arrive largely assembled and require far less onsite piping, fabrication, and coordination. VRF systems, while more installation-intensive than RTUs due to extensive refrigerant piping and control work, still maintain lower installation costs compared to hydronic systems because they do not require pumps, water piping, or central plant infrastructure. As a result, the cost breakdown for air-based systems leans more toward equipment than installation. The RTU systems demonstrate the lowest total first costs, aligning with their reputation as the most economical HVAC option from a first cost standpoint.

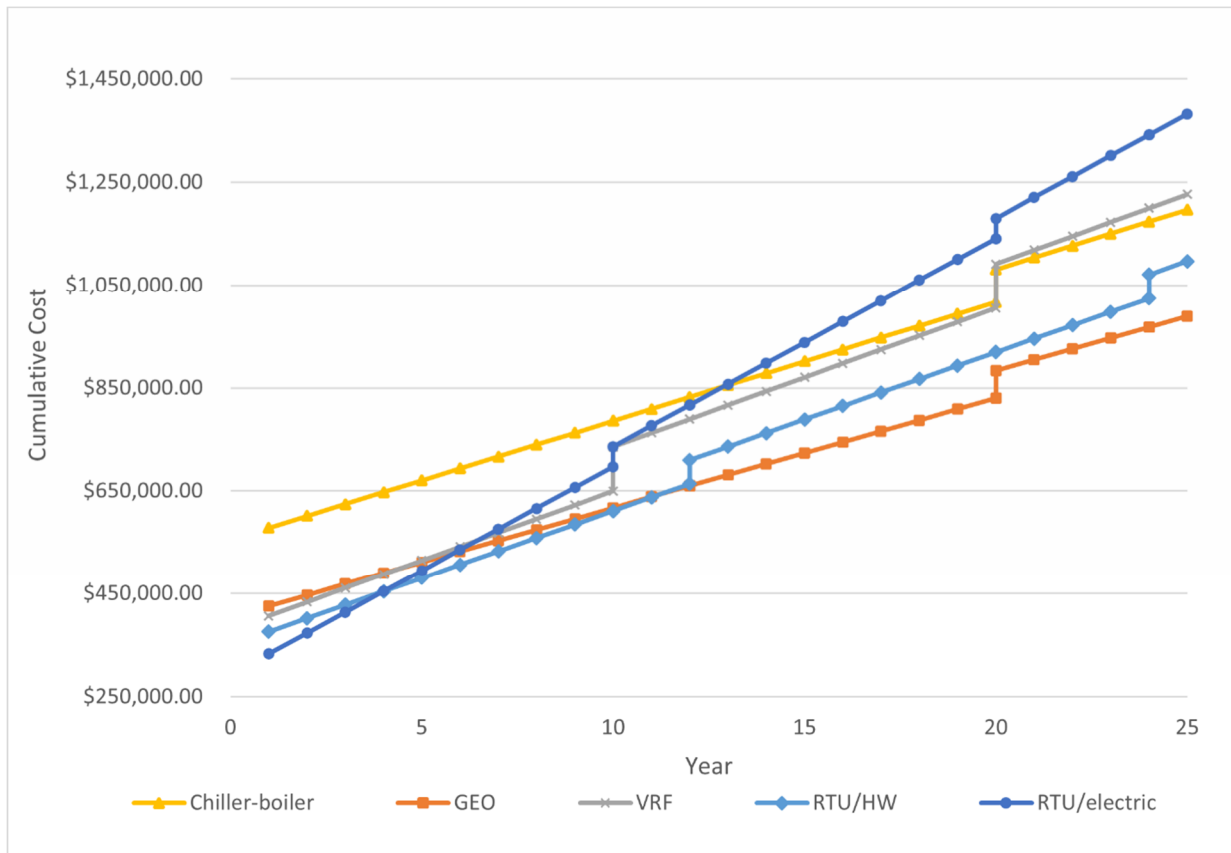


FIGURE 9: CUMULATIVE LIFECYCLE COSTS

The recurring annual costs of a project can reveal the true financial burden over time that first-costs fail to embody. Systems with the lowest entry cost often face the steepest cumulative cost growth over time. Figure 9 shows the cumulative costs over a 25-year period, including major maintenance and replacement costs at various intervals. The timing of the replacements are estimates based on typical historical lifecycles of each system. ASHRAE has national data with typical lifecycles for each of the specified systems; however, the data is not regional, and equipment in Wisconsin’s climate tends to have shorter lifespans. Since major replacements would typically reuse existing infrastructure (ductwork, piping, controls, etc.), only a portion of the original equipment cost was applied to each replacement cycle. The outdoor based systems (RTUs and VRF) had an estimated replacement of around 10-12 years. Hydronic systems were modeled with longer 20-year major component life cycles. The replacement costs of the monthly utility costs were derived from energy simulation, and the maintenance costs were estimated based on data from BEST Energy modeling software. The slope of each curve reflects the relative operating cost magnitude of each system—steeper slopes corresponding to higher ongoing utility and maintenance costs—while the step changes represent major replacement events. As seen in Figure 9, low first costs can be misrepresentative of long-term system price as annual utility bills begin to accumulate. The RTU system with electric reheat (despite having the lowest initial cost) shows the highest 25-year cost due to the high utility charges associated with electric resistance heating. The geothermal system had the lowest 25-year cost due to its low maintenance costs, long lifecycle, and high efficiency. Overall, the analysis demonstrates how viewing lifecycle costs reshapes the

perceived value of higher-efficiency systems, showing that systems with longer lifespans and lower utility costs can offset higher first costs over time.

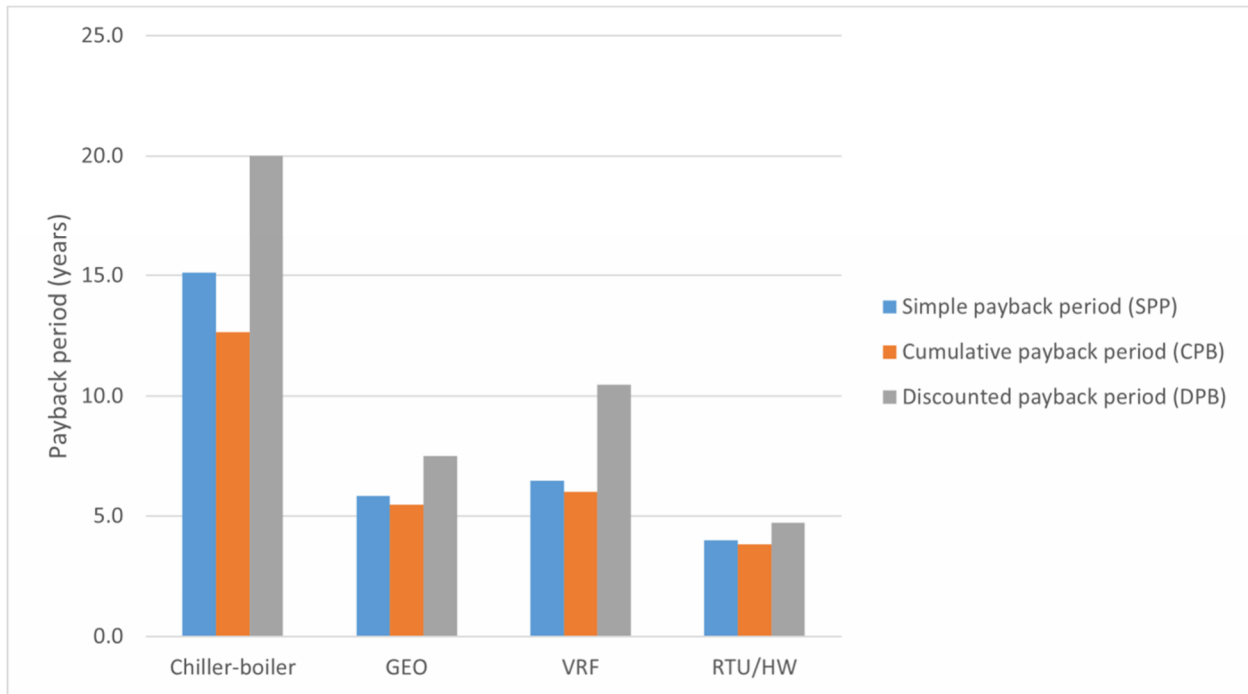


FIGURE 10: PAYBACK PERIODS BY SYSTEM

A lifecycle cost analysis was performed to evaluate the economic performance of each HVAC system over a twenty-five-year period, using rooftop units with electric VAVs as the baseline system. This analysis compares the incremental first cost of each alternative against its corresponding energy and maintenance savings to determine the payback period—the length of time required for the additional capital investment to recover its cost. There are three types of payback periods used in Figure 10. The simple payback period is simply the additional first cost amount divided by the annual savings. The cumulative payback period is the amount of time it takes for the total net cash flow (undiscounted) to equal the total net cost of the system. While cumulative payback period offers a quick benchmark, it overlooks discounting, which adjusts future cash flows to their present value and provides a more accurate financial narrative. The discounted payback period is the amount of time it takes for the discounted cumulative net cash flow to equal the discounted total net cost of the system. All three metrics help frame cost recovery, but the discounted payback period offers the most realistic financial insight because it evaluates savings in present-value terms.

The results, summarized in Figure 10, indicate that the rooftop units with hot water reheat achieved the shortest payback period, followed by the geothermal system and the VRF configuration. Conversely, the chiller/boiler system exhibited a significantly longer payback period primarily due to its high installation and equipment costs combined with moderate operational savings. These findings highlight that while hydronic systems can offer superior long-term efficiency, their economic viability is highly sensitive to first cost, project-specific utility rates, and the scale of the building load. It should also be noted that the relative payback observed here applies to the specific building size analyzed. For larger or more continuously loaded facilities, systems such as the chiller/boiler and geothermal

configurations may achieve shorter payback periods and improved lifecycle costs due to their higher efficiency at scale.

Simulation Versus Reality

Up to this point, all energy results in this study have been based on predicted performance from the HAP simulations. A key objective of the analysis, however, is to compare these modeled outcomes against the actual installed system and its associated costs and incentives. One of the most common questions is whether the project qualified for federal and utility incentives—and how those incentives impacted the overall cost.

The total installed cost of the geothermal system was \$679,295, which is consistent with the itemized estimate of \$705,648 shown in Figure 7, especially when considering inflation. The building owner qualified for and claimed the 30% Investment Tax Credit (ITC) along with the 10% Domestic Content adder, resulting in a combined federal tax credit of \$271,718. In addition to the 40% federal incentive, the project received a Focus on Energy payment of \$16,920. Altogether, incentives covered 42.4% of the project cost, reducing the net post-incentive cost to \$390,657.

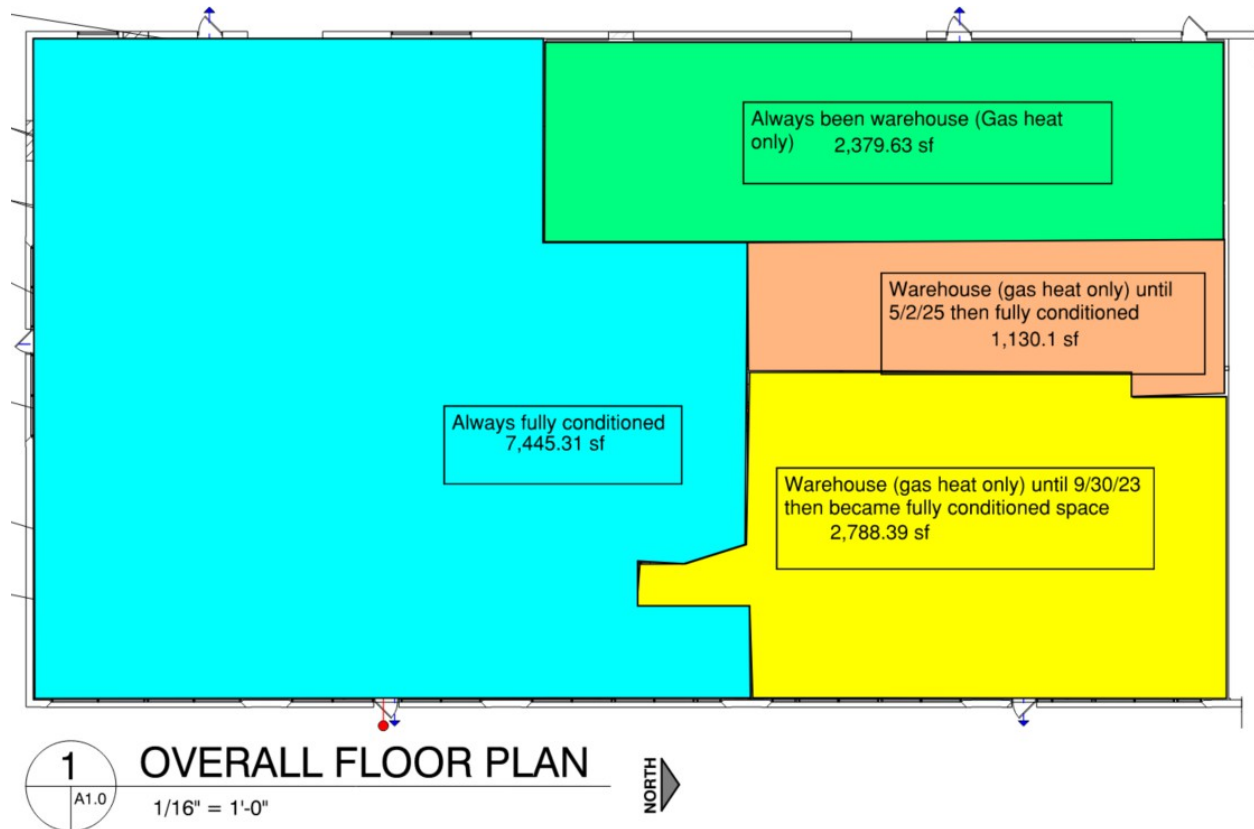


FIGURE 11: FLOOR PLAN CONDITIONED SPACES

The next most prominent question is how much energy the owner saved compared to the energy model predictions. Quantifying this proved to be significantly more challenging than expected. Although the utility history was compiled, the building’s load profile changed twice during the study period due to major renovations. Prior to the geothermal system installation, the building was served by

a VRF system which conditioned a total of 7445 sq ft of office space. The remaining 6297 sq ft was warehouse space that didn't have air conditioning, and the heating was provided by a gas fired makeup-air unit. When the geothermal system was installed, the building also underwent a renovation that added 2,788 sq ft of conditioned office space, increasing the total conditioned area to 10,243 sq ft. A subsequent 2025 expansion added another 1,130 sq ft of office space.

As more square footage is conditioned, total energy consumption increases, so comparing raw utility data across years—without adjustment—would misrepresent actual system performance. The additional office areas also introduced more VRF occupants, computers, and plug loads, further increasing electrical usage independent of the HVAC system. For these reasons, a direct year-over-year energy comparison was not possible.

To create a workable baseline, we instead took the VRF-era utility profile from January 2022 through January 2023 and overlaid it onto Figure 12. To account for the added load from the expanded building area, a correction factor was applied to the predicted VRF energy-use trend (shown in orange). This correction factor was calculated as a multiplier based on the ratio of conditioned square footage before each renovation to the square footage afterward. This allowed us to approximate what the VRF system would have consumed if it had been required to serve the expanded building area.

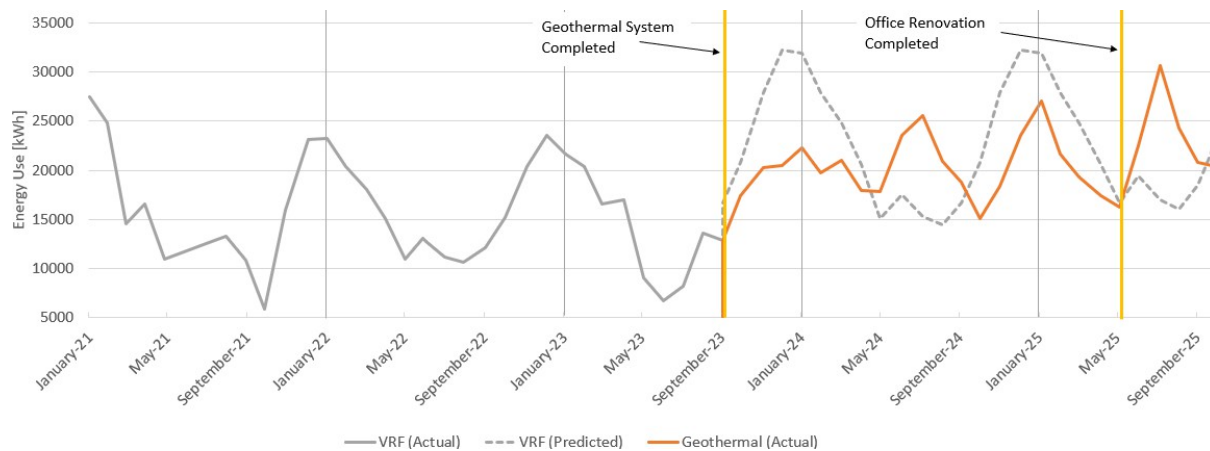


FIGURE 12: HISTORICAL ELECTRICAL USE AND PREDICTED VRF USAGE

The utility history prior to the geothermal installation shows seasonal swings that align closely with the VRF model predictions from Figure 6. Winter electrical consumption is highest due to heating load, while summer consumption is comparatively low. However, after the geothermal installation, there is a similar periodic trend, but energy consumption peaks in both the summer months and the winter months. The lowest energy consumption is during the shoulder seasons where the outside air temperatures are closest to indoor setpoints.

Comparing the post-install geothermal energy use to the corrected VRF baseline reveals that the geothermal system consistently uses less energy during the winter months. This outcome is expected: VRF systems lose heating capacity and efficiency as outdoor air temperatures drop, while geothermal systems benefit from stable, warmer loop temperatures that remain well above winter air temperatures. The geothermal system therefore requires less compressor energy to deliver the same heating load.

However, one notable result is that the predicted VRF energy use is much lower than the actual geothermal energy use during the summer months. This contradicts our initial modeling expectations, which predicted only a modest rise in summer energy use and a much larger increase in winter as shown in Figure 6. Instead, actual electrical use during the summer is comparable to winter usage. A likely cause of this deviation is dehumidification and reheat energy. In summer operation, the geothermal fan coils are dehumidified by cooling air to approximately 55°F to remove moisture, then reheating the air back to room temperature even when the space is already satisfied for sensible cooling. VRF provided limited or no active dehumidification and therefore requires no reheat during summer operation. Because the HAP model was unable to account for this style of operation, the geothermal system’s actual summer consumption is higher than predicted in Figure 6.

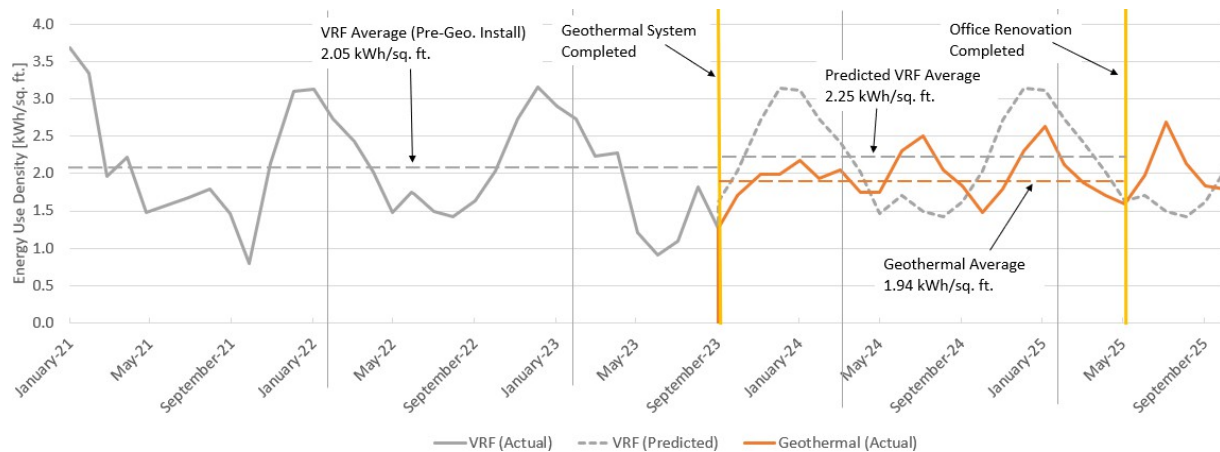


FIGURE 13: ELECTRIC USAGE BY SQUARE FOOTAGE

Figure 13 shows that the geothermal system maintained a similar average kWh/sq ft to the VRF system prior to renovation. However, the geothermal system operated within a much tighter maximum–minimum band. This narrower range reflects the stability of a ground-source system. Loop temperatures vary far less than outdoor air temperatures, leading to more consistent compressor performance and smoother seasonal energy profiles.

The figure also reinforces patterns observed in Figure 12. Summer energy use per square foot remains noticeably higher than winter use, likely due to the dehumidification and reheat requirements discussed earlier. However, because the data is normalized, it becomes clear that the geothermal system’s wintertime energy intensity is significantly lower than what the VRF system would have required, even after applying the square-footage correction factor. This suggests that geothermal heating is more efficient per unit of conditioned space.

Another important insight is the reduced volatility in kWh/sq ft throughout the year. The predicted VRF profile shows sharper peaks and valleys, highlighting its sensitivity to outdoor ambient conditions. By contrast, the geothermal data exhibits smoother transitions between seasons and fewer extreme values. This operational stability is an advantage for both energy planning and equipment longevity, as smaller swings in load reduce mechanical stress and allow the system to operate closer to its optimal efficiency point for more hours of the year. Even though the geothermal system consumed more energy during the summer than we anticipated, its summer kWh/sq ft still falls within the expected performance band for the VRF system. This suggests that, despite the unmodeled

dehumidification and reheat, geothermal cooling performance remains strong—and its heating performance continues to show a noticeable efficiency benefit over VRF.

Basis for System Selection

Following the technical and financial analysis, the geothermal system was selected as the most balanced solution for the office building. Although it ranked second in both modeled energy efficiency and simple payback, its overall controllability, longevity, and incentive eligibility made it the most advantageous long-term investment. The geothermal design benefits from a constant ground-source temperature, maintaining reliable performance in both heating and cooling modes without the seasonal efficiency swings that affect air-source systems such as VRF or rooftop units. In addition, some air source systems are subject to defrost cycles, which geothermal does not need.

The project also capitalized on significant federal and state incentives. Geothermal technology qualifies for the highest tier of funding through the Federal Investment Tax Credit and Wisconsin's Focus on Energy program. These incentives substantially offset the higher first cost and improved the financial return of the system. Beyond the financial advantage, the bore field itself represents a long-term infrastructure investment with a projected lifespan exceeding fifty years. This allows future replacement or upgrade of terminal and plant components without disturbing the ground loop, effectively future-proofing the building for the next generation of heat pump or chiller technologies.

From an operational standpoint, the geothermal system provides a high level of comfort and controllability. The 4-pipe fan coil configuration allows true multi-zone operation with simultaneous heating and cooling, offering occupants individualized comfort and humidity control. The fan coil system also supports improved indoor air quality through higher-efficiency filtration than the VRF systems. Additionally, the modular design provides inherent redundancy—dual chillers, distributed fan coils, and independent zones ensure continued operation even during maintenance or partial system failure.

The decision also factored in the owners' experience with their existing VRF system. The prior installation experienced recurring maintenance challenges, including component failures, and service complexity that impacted reliability and increased operating costs. Transitioning to a water-based geothermal platform mitigates these issues and simplifies long-term maintenance due to the brand-agnostic interchangeability of system components. Furthermore, the all-electric geothermal system aligns with ongoing electrification and decarbonization trends, reducing the building's reliance on fossil fuels and exposure to future energy policy shifts. Altogether, the geothermal system was chosen not only for its energy and financial merits but also for its resilience, sustainability, and ability to support the owners' long-term operational and environmental goals.

Conclusion

The geothermal system selected for the Waukesha office offers the best balance of long-term performance, total cost of ownership, and sustainability. While its first cost was higher than the rooftop unit systems and the chiller boiler system, the lifecycle analysis confirmed that those premiums are offset by reduced utility expenses, lower maintenance, and long equipment life. Energy modeling and cost analysis showed a consistent reduction in annual utility expenses compared to the other systems, resulting in one of the lowest 25-year cumulative lifecycle costs among all options evaluated.

The primary drivers behind the decision to use geothermal were the exceptional operating efficiency, long equipment lifespan, and stability across seasonal extremes. In contrast with air-source systems, the geothermal design benefits from the consistent ground temperature, enabling consistent COPs for both heating and cooling. This stable performance yields predictable energy use and utility costs year-round, especially important in Wisconsin's heating-dominant climate. The system's 4-pipe fan coil configuration further enhances comfort and control, allowing simultaneous heating and cooling across zones.

Financially, the geothermal system became highly competitive after factoring in federal and state incentives. The project qualified for a 40% Federal Investment Tax Credit (30% base credit plus 10% domestic content adder) and a \$16,920 focus on energy rebate, effectively offsetting a large portion of the installation cost. When combined with accelerated depreciation and Section 179D deductions, these incentives significantly shortened the payback period and improved the present value of the system. On top of that, the bore field is expected to last 50+ years, allowing for future replacement or upgrades, further enhancing the long-term financial benefit.

Beyond financial and technical performance, the project delivers measurable environmental and occupant benefits. The all-electric design eliminates on-site fossil fuel combustion. Occupants benefit from quieter operation, improved thermal comfort, and enhanced indoor air quality—key attributes for a productive office environment. From a maintenance and reliability perspective, the geothermal system introduces lower long-term service requirements. Dual reversible chillers and redundant pumps ensure redundancy and longevity. Ultimately, this project demonstrates how geothermal technology can provide a durable, efficient, and environmentally responsible solution for commercial buildings in cold climates.

Appendix (Separate Document)

A full technical appendix containing detailed modeling inputs, cost worksheets, assumptions, incentive calculations, utility-bill comparison, and additional supporting figures is available as a separate document or online [here](#).