Evaluation of Emerging Sustainable Residential Construction Technologies in the Twin Cities Metro Area

by

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ABSTRACT

The intent of this study was to identify the most viable among a proposive sample of emerging sustainable construction technologies with respect to the Twin Cities Metropolitan Geographic Area. With space heating and space cooling accounting for such a significant portion of energy consumption in Twin Cities homes, a representative sample of homes was analyzed for annual heating and cooling loads. For each home a series of heating, ventilation, air conditioning (HVAC) and envelope equipment was modeled in order to provide data for various sustainable home construction technologies. The result was a specific amount of energy savings from baseline construction methods for each sustainable technology. The study found that integrated geothermal heat pump and radiant conditioning systems have a far greater impact on energy savings than the construction methods evaluated. Nevertheless, insulated concrete forms provided the greatest energy savings within the proposive set of construction methods. The greatest amount of space conditioning energy savings of all configurations tested was 73.48% using an integrated geothermal heat pump and radiant conditioning system, structural insulated panel wall construction, aerosol air infiltration prevention, and insulated concrete form basement construction. The results of the study were used to determine areas for further research and to provide awareness within the Twin Cities construction enterprise to determine the most viable technologies that contractors, municipalities, and citizens should prioritize moving forward.

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CHAPTER 1

INTRODUCTION

As home construction technology improves, the feasibility of building net zero homes is constantly growing. Much has been written about the value of reducing carbon emissions from the built environment. For that reason, municipalities and governments increasingly are looking to instantiate net-zero construction into building codes and standards (Eschwass, 2019). Individuals are seeing the benefit as well as they look to eliminate utility bills that cost Americans between 4.8-11% of their incomes (“Introduction to CE Data Products”, n.d.). The societal impacts of net-zero construction are substantial. Carbon emissions are eliminated, utility infrastructure can be reduced, and reliance on fossil fuels can be averted. There are benefits from a resident’s perspective as well: improved indoor air quality, reductions in drafts and uneven temperatures in a home, more effective moisture control and waterproofing, and of course the reduction in energy bills. With the goal of net-zero construction as an industry standard in the future, it is imperative now to consider how builders will have to adapt to meet the net-zero construction challenge.

That challenge requires an understanding of the unique headwinds that exist in the construction industry. Among these challenges are the competitiveness of practitioners, repetitive nature of the industry, prevalence of small companies, and fragmented professional networks. All contribute to the challenge of transitioning emerging technologies into the established supply chain. Albassami, Ali, and McCoy (2015) lay out the problem well, “In residential construction, innovation is particularly relevant to the world’s growing demand for affordable and sustainable housing. Innovations that successfully diffuse between established and emerging residential markets may offer significant benefits to all stakeholders, especially those developing the technology. However, residential construction is known for its resistance to adopting innovation, which partially addresses the characteristics of the residential construction industry and market, supply chain, and risk tolerance." For those looking to bring technology to residential construction there exists a requirement to understand the technology but perhaps even more importantly the opaque nature of supply chain integration (Albassami et al., 2015).

In addition to understanding the nature of the residential construction industry, the net-zero challenge requires a geographic perspective as well. Environmental variables including temperature, humidity, wind, precipitation, soils, and other physical factors necessitate a tailored approach to net-zero home construction in respective geographies. The technologies that should be prioritized in a cooling dominated climate like Texas will not necessarily be relevant in a heating dominated climate like Minnesota. To alleviate the concerns of a Minnesota builder, a technology must demonstrate its relevance for local conditions (ASHRAE, 2018).

Having established the geographic and challenging nature of residential construction, research may begin to determine which sustainable construction technologies should be prioritized for a specific market. With space heating and cooling accounting for roughly 50% of all residential energy consumption, reducing HVAC loads becomes a foundational component of any builder's strategy to accomplishing net-zero construction. Furthermore, the components of a home that affect heating and cooling loads must be carefully integrated into design and project delivery planning in order to be effective. The builder's choice for exterior wall construction including basements is perhaps the most important decision he or she will make when attempting a net-zero construction. Once HVAC loads have been established the builder must determine the most effective way to deliver the required space heating and cooling (Anderson et al., 2008).

Sustainable construction technologies exist in each of these areas but are far from becoming common practice. In order to identify for the Twin Cities Metro area in Minnesota, this study will look at a proposive set of these sustainable technologies in order to provide a basis for prioritization moving forward.

CHAPTER 2

LITERATURE REVIEW

Barriers to Adoption

The National Renewable Energy Laboratory (2008) Technical Report titled "Maximizing residential energy savings net zero energy home technology pathways" published in 2008 took an in depth look at the pathway towards integrating Sustainable Technologies (STs) for construction contractors. The first significant contribution relevant to this study was the identification of a three-step ST integration process. After meeting minimum contractor, engineer, and user requirements and subsequent case study validation, the third step in ST integration was expressed as follows, "The field training, quality assurance/quality control, commissioning, and operations and maintenance requirements for the technology must be integrated as part of a production construction process to ensure that potential savings and benefits are achieved when the technologies are broadly implemented." The detailed definition provides a standard for ST evaluation that proves useful today in evaluating the successes and failures of emerging products, processes, and techniques. The second relevant contribution to this study from the 2008 NREL report was the identification of key areas requiring technological progress to eventually reach the goal of widespread near net-zero construction. The areas identified included high-R Wall Assemblies, cold climate domestic hot water, cold climate R-10 window assemblies, very high-performance A/C Systems, and miscellaneous electrical energy use reduction. Finally, with the first two contributions in mind, NREL's identification of builders as "residential system integrators" indicates careful attention should be dedicated to the project managers and general contractors who will make decisions with regard to integrating STs in their operations (Anderson et al., 2008).

Formally adding more details and anecdotal evidence from field interviews, Dadzie, Runeson, Ding, and Bondinuba (2018) discussed barriers to adoption with a sample of architects, engineers, project managers, and property managers (Dadzie et al., 2018). Such barriers identified from their work included unpredictability of investment recuperation, inconsistent results as compared with product and material advertisements, perceived hidden costs of using a new technology, as well as the challenges in integrating sophisticated technologies across contractors and schedule timelines (Dadzie et al., 2018). ASHRAE, in their industry standard publication for sustainability titled "ASHRAE Green Guide" (2018), identified a similar need to target the field-level installers of sustainable technology to promote more widespread acceptance (ASHRAE, 2018).

Cold Climate Net-Zero Case Studies

Specific geographies present specific opportunities and challenges to builders and contractors related to soil conditions, temperature, humidity, sunlight, and many other factors (ASHRAE, 2018). In order to provide relevant data to builders and contractors in a specific area, STs must make sense for specific geographic locations. There exists a substantial number of case studies of net-zero homes constructed in Minnesota and other cold climates throughout the world. Net-zero projects registered by the International Living Future Institute in Minneapolis, MN and Roseville, MN were early proofs of net-zero viability using geothermal heat pumps, radiant floor heating, heavily insulated building envelopes, and air tightness (Minneapolis, 2013; Ohm, 2013). Another project in Minnesota, near lake Itasca, used a similar set of technologies to accomplish net-zero energy on a large residential project for the University of Minnesota (Nemer, 2013). Henderson (2013) looked at a number of case studies throughout Canada and New York and reached the conclusion the most economical method of achieving energy efficiency was to prevent loss of energy as opposed to more efficiently producing it. In context, that required providing a tight, well insulated envelope before moving to efficient HVAC systems (Henderson, 2013).

Building Envelope

Space heating and cooling in 2019 still accounts for roughly 30% of all energy consumption in the United States (US EIA, 2019). The principal method of reducing heating and cooling loads in homes is to improve the building envelope (Henderson, 2013). This means increasing R-values for exterior walls and roofs but also by making homes air tight (Anderson, 2008). According to the US Environmental Protection Agency, 25-40% of all space heating and cooling energy consumption is lost to air leakage ("Air Sealing", 2019). Jimenez's study of air leakage in residential buildings showed that an ACH50 score of 1 had roughly half the heating energy demand of a building with ACH50 score of 6 (Jimenez, 2013). That disparity is likely to be even higher in colder climates. In response to the need for airtight homes, HVAC duct sealing technology has been reworked for whole house application to great success in the United States using aerosol infiltration reduction treatments ("The New American Home", 2018). The construction methods of a home play a significant role in airtightness and R-value as well. One significant emerging construction method is the use of Structural Insulated Panels (SIPs) (Abang, 2013). According to their study of SIPs, the benefits of this construction method are promising for sustainability for their high R-values, ease of building air tight envelopes, labor savings, reduction of waste, and rapid construction completion time (Abang, 2013). Li, Yu, Sharmin, Awad, & Gül conducted an in-depth study of wall assemblies that found spray foam to be an effective technique for maintaining high R-Values and low relative humidity while Structural Insulated Sheathing performed well as an insulator but led to moisture problems in the wall cavity during the cooling season (Li et al., 2016).

HVAC Systems

As it relates to the efficiency of emerging space heating and cooling options, there appears to be ample studies from industry providers and designers with relatively little attention from an academic approach. This is likely due to the straightforward nature of efficiency claims of HVAC products and their industry verified commissioning processes. However, a significant amount of academic research has been dedicated to the topic of geothermal heating and cooling along with radiant versus ventilated delivery methods. Wallace (2014) found that a radiant heating and cooling system combined with a geothermal heat pump can reduce HVAC power consumption by 60% (Wallace, 2014). Hesaraki, Bourdakis, Ploskić, & Holmberg (2015) similarly found that geothermal heating and cooling systems consistently reduce power draws by 67-75% (Hesaraki et al., 2015). From a user perspective, Baird found that feedback for radiant space heating and cooling was markedly positive and consistent (Sayig, 2015). A much less intensive, albeit potentially viable, technology is the ductless mini-split system which Roth (2006) claims creates a 20% reduction in energy consumption over conventional space conditioning systems (Roth, 2006).

CHAPTER 3

RESEARCH METHODOLOGY

Manual J Calculations

The purpose of this study was to evaluate a proposive list of emerging sustainable residential construction technologies based on their ability to reduce heating and cooling energy consumption in Twin Cities homes. In order to accomplish this, the Air Conditioning Contractors of America (ACCA) Manual J heating and cooling load calculation process was used (Manual J, 2016). Manual J calculations are widely used as a precise method of determining heating and cooling loads for specific detached homes while taking into account local conditions. They provide the most credible and flexible method for evaluating changes in HVAC efficiency for the hypothetical scenarios of this study (Manual J, 2016). Utilizing that process, 12 homes were identified where a series of ST combinations would be evaluated for performance based on Manual J calculations. For each home, 12 combinations of STs were configured, and Manual J calculations were conducted for each configuration. In total, 144 Manual J calculations were conducted. A baseline configuration was included with no STs in order to provide a reference for comparison. The baseline configuration is summarized in the table below:

Table 1

Baseline Construction Features for Reference

Exterior Walls	2x6 stud-framed walls with R-19 insulation
Foundation Construction	8” concrete or concrete brick foundation walls
Air sealing	“Average” home air tightness

The load calculation software used to conduct Manual J calculations was CoolCalc.com. For each home that was sampled, address information for the home was entered and floorplates for the homes were entered by conducting a map trace from overhead imagery. It's important to note that for each home, a block load calculation was conducted as opposed to room-by-room calculations. While the block loads will provide an accurate assessment of the relative changes as construction features are altered, the specific interior configurations of each home may create variances in calculated heating and cooling loads. For each home the ACCA-recognized Minneapolis-St. Paul International Airport weather station data was used for determining heating and cooling design temperatures which were -8* Fahrenheit and 88* Fahrenheit respectively (CoolCalc Manual J, 2018).

Conversion to Annual Heating and Cooling Energy Consumption

Before comparing relative energy savings, heating degree days and cooling degree days with a base indoor temperature of 65* Fahrenheit were used based on local weather conditions to determine overall annual energy consumption for heating and cooling. Calculations for converting from heating and cooling loads to annual energy consumption are shown below:

$$Annual\ Heating\ Energy\ Consumption = \frac{Heating\ Load\ \left(\frac{BTU}{Hr}\right) * HDD * 24hrs}{(Base\ Temp - Design\ Temp) * 3412.12\left(\frac{BTU}{KWH}\right)}$$

$$Annual\ Cooling\ Energy\ Consumption = \frac{Cooling\ Load\ \left(\frac{BTU}{Hr}\right) * CDD * 24hrs}{(Base\ Temp - Design\ Temp) * 3412.12\left(\frac{BTU}{KWH}\right)}$$

In order to accurately evaluate the overall annual system performance of each ST, the annual heating and cooling loads were added to create an annual space conditioning load for comparison to the baseline construction features.

Proposive Sustainable Technologies and Configurations

The proposive list of STs included two exterior wall construction technologies, structural insulated panels and vapor barrier insulated sheathing. SIPs and insulated vapor barrier sheathing were not configured together as they are mutually exclusive wall construction technologies. Insulated concrete forms and aerosol air infiltration treatment were the other technologies evaluated. A summary of the configurations of STs that were used are shown in the table below:

Table 2

Proposive ST Configurations for Evaluation

ST Configurations for Evaluation	SIPs	Ins. VB Sheathing	Aerosol air infiltration treatment	ICFs
Baseline	No	No	No	No
Config1	Yes	No	No	No
Config2	No	Yes	No	No
Config3	No	No	Yes	No
Config4	Yes	No	Yes	No
Config5	No	Yes	Yes	No
Config6	No	No	No	Yes
Config7	Yes	No	No	Yes
Config8	No	Yes	No	Yes
Config9	No	No	Yes	Yes
Config10	Yes	No	Yes	Yes
Config11	No	Yes	Yes	Yes

For each ST, the Manual J calculation was altered in a specific way to most closely mimic real-world performance. For Structural Insulated Panels, wall construction consisted of 6.5” insulated foam panels with an R-53 attic ceiling. Without using aerosol air infiltration prevention, baseline air tightness for SIPs was considered semi-tight because of the natural tightness of the construction method. A similar treatment was used for Insulated Vapor Barrier Sheathing where baseline air tightness was considered “semi-tight”. The Manual J input for insulated vapor barrier sheathing included 2x6 wall construction with R-19 batts in addition to R-6 board insulation and a standard R-25 attic ceiling. For aerosol air infiltration treatment, it was assumed the aerosol process would be run until passive house standards were met which is equal to 52 ELA or roughly 0.6 ACH50. Insulated concrete forms for basement construction were assumed to have R-34 insulation.

Home Selection

The homes chosen to be evaluated are not necessarily a comprehensive representation of Twin Cities homes but rather what was made available through construction access. Out of the homes evaluated, conditioned space ranged from 1,870 sq-f to 6220 sq-f with an average of 3795 sq-f. Square footage was calculated based on home dimension input in the Manual J calculation and average square footage was calculated as the mean of the 12 homes evaluated. Addresses included municipalities of Minneapolis, Saint Paul, Minnetonka, Mendota Heights, Golden Valley, Arden Hills, Edina, Stillwater, Waconia, and Elko. Six of the 12 homes were in urban settings, five of the 12 were in suburban settings, and one was located in a rural setting. All but one of the homes included a basement.

CHAPTER 4

RESULTS AND ANALYSIS

Regarding Construction Features

The result output from the research included heating and cooling loads and annual space conditioning energy consumption for all 12 configurations of construction features for each respective home evaluated. Using the baseline configuration as a reference, a net improvement over baseline was calculated as a percentage for each configuration on each home. The results are summarized in the table below:

Table 3

Summarized Efficiency Improvement Results

	4521 Beard Avenue	14400 Tonka Downs Drive	1950 West Highland Parkway	1746 Trail Road	1515 Oregon Ave	1548 Arden Place	296 Meadow Lane	8104 Morgan Ave	6104 Crescent Drive	425 Lakeview Terrace	4975 Wilderness Lake	1068 Lombard	Averages
Square Footage	4467.2	3745.2	4992.5	2405.6	3250l.8	4152.1	1870.5	3825.7	4428.8	2910.4	2726	6220.1	3794.918182
Baseline	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Config1	11.54%	11.49%	12.95%	5.37%	6.27%	12.94%	9.95%	11.01%	12.18%	11.38%	13.72%	16.73%	11.29%
Config2	6.70%	6.79%	9.12%	5.48%	6.41%	7.68%	6.56%	6.43%	7.46%	6.91%	7.77%	9.70%	7.25%
Config3	4.22%	3.95%	8.71%	1.17%	1.45%	6.20%	-0.85%	2.87%	4.94%	4.07%	5.99%	3.66%	3.86%
Config4	11.92%	12.06%	16.33%	3.32%	4.30%	15.25%	5.51%	10.21%	13.60%	11.90%	15.40%	22.38%	11.85%
Config5	7.08%	7.36%	12.50%	3.43%	4.45%	10.00%	2.11%	5.62%	8.88%	7.43%	9.44%	11.84%	7.51%
Config6	29.38%	18.51%	18.78%	36.84%	30.56%	22.52%	30.57%	29.15%	19.75%	24.08%	0.00%	7.70%	22.32%
Config7	40.92%	30.00%	31.74%	42.22%	36.83%	35.46%	40.52%	40.16%	31.93%	35.46%	13.72%	24.43%	33.62%
Config8	36.08%	25.30%	27.91%	42.33%	36.97%	30.20%	33.54%	35.58%	27.21%	30.99%	7.77%	17.41%	29.27%
Config9	33.60%	22.46%	27.49%	38.02%	32.01%	28.72%	29.71%	32.02%	24.69%	28.15%	5.99%	18.52%	26.78%
Config10	41.29%	30.57%	35.12%	40.17%	34.86%	37.77%	36.07%	39.36%	33.35%	35.89%	15.40%	30.09%	34.16%
Config11	36.45%	25.87%	31.28%	40.28%	30.73%	32.52%	32.68%	34.77%	28.63%	31.51%	7.77%	23.06%	29.63%

Configurations were laid out according to table 3.2. Results from each residence including calculated heating load, calculated cooling load, and annual power consumption can be found in Appendix A.

Configuration 10 which included structural insulated panels, aerosol treatment, and insulated concrete form basement construction resulted in the greatest overall improvement over baseline at 34.16%. Looking at the average incremental improvements over baseline construction by sustainable technology, results are summarized in the table below:

Table 4

Relative Energy Savings Over Baseline Construction

Structural insulated panels	11.29%
Insulated vapor barrier sheathing	7.25%
Aerosol air infiltration treatment	3.86%
Insulated concrete forms	22.32%

Comparing the two exterior wall construction types, SIPs and insulated vapor barrier sheathing, SIPs provided nearly a 4% improvement. Much of this improvement is likely due to the improved ceiling insulation that is not provided from insulated vapor barrier sheathing. While infiltration reduction provided some improvement in efficiency, its impact was hardly substantial as compared with advanced exterior wall and foundation construction. Insulated concrete forms for foundations provided the largest improvement over baseline construction at 22.32%. While combining sustainable technologies in all cases resulted in a cumulative improvement in overall efficiency, the components never provided synergetic results. In other words, the combination of multiple sustainable technologies never resulted in an improvement that was greater than the sum of the respective technologies.

Analysis of HVAC Improvements

Having established the capability of space conditioning improvements of construction features, it is worth analyzing them with respect to efficiency improvements of HVAC technologies. Drawing from the research from Wallace (2014) and Heseraki (2015), a conservative estimate of HVAC efficiency improvement from an integrated geothermal heat pump and radiant heating and cooling system would likely provide a 60% improvement in energy consumption over conventional HVAC systems. Similarly, Roth (2006) concluded that mini-split systems could provide a 20% improvement over conventional systems. By overlaying these improvements with the construction technologies listed above, overall system improvements can be evaluated. The results of this analysis are shown below:

Table 5

Efficiency Improvements Combining HVAC and Construction Features

	Combined Improvement of STs and GSHP Radiant System	Combined Improvements of STs and Mini-Split System
Baseline	60.00%	20.00%
Config1	64.43%	29.04%
Config2	62.87%	25.80%
Config3	61.33%	23.09%
Config4	64.55%	29.48%
Config5	62.83%	26.01%
Config6	68.94%	37.86%
Config7	73.37%	46.89%
Config8	71.65%	43.42%
Config9	70.58%	41.43%
Config10	73.48%	47.33%
Config11	71.66%	43.70%

This analysis shows that from the proposive set of sustainable technologies the greatest degree of space conditioning efficiency improvements comes from a GSHP-radiant system combined with structural insulated panels, infiltration reduction, and insulated concrete form foundations. The potential energy savings of that system is 73.48%. Though the GSHP-radiant system has great potential energy savings, it is also worth noting that mini-split system with sustainable technology construction components can nearly reach a 50% reduction in space conditioning energy consumption.

Areas for further analysis

The results of this study provide an understanding of the potential impact of current emerging sustainable technologies for Minnesota builders. More research, however, is necessary to understand the economic viability of each technology. Payback periods related to each technology based on their savings in energy would be an important study if the costs of installation or integration in a new build could be determined on a local level.

Another important study at this point would be to survey local builders who have had experience with the technologies from this study. It is likely that each technology poses benefits and drawbacks from a delivery perspective which will be crucial information if these advanced technologies are to eventually proceed through the three phases of construction technology integration as laid out by NREL (2008).

While the proposed technologies in this study have been and will continue to be used on some scale in the Twin Cities moving forward, there are certainly more technologies worth evaluating. As new products and construction methods emerge and become integrated with Manual J software, it will be important for builders to constantly evaluate them with a local perspective in order to gain an understanding of their potential impact on energy consumption.

CHAPTER 5

SUMMARY AND CONCLUSIONS

The purpose of this study was to provide data about the relative weight and priority to be placed on a proposed list of sustainable technologies for residential construction in the Twin Cities. The study intended to provide awareness to prospective builders, homebuyers, developers, and citizens about the energy savings capability of current advanced technology as a basis for further research and continued development of energy efficient designs and project delivery methods. The research methodology was intended to create a repeatable framework for evaluating new technologies that emerge in the future by employing the industry-standard Manual J calculations.

In this study, the results showed that integrated geothermal heat pumps and radiant floor heating and cooling provide a nearly essential reduction in space conditioning load given the large variance between base temperature and design temperature in Minnesota winters. Combined with advanced construction techniques to create insulated, air-sealed exteriors, space conditioning energy savings can reach nearly 74% over conventional construction methods using the STs in this study. In scenarios where geothermal systems may be prohibitive, mini-split systems with advanced construction features approach 50% space conditioning energy savings and may prove to be a viable option for net-zero design as well.

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APPENDIX A

SPACE CONDITIONING IMPROVEMENT EVALUATIONS BY ADDRESS

4521 Beard Avenue								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	99021	27734	78658.41301	7818.227872	86476.64088	0.00%	60.00%	20.00%
Config1	87964	23491	69875.16428	6622.124142	76497.28842	11.54%	64.62%	29.23%
Config2	92306	26104	73324.27941	7358.730092	80683.0095	6.70%	62.68%	25.36%
Config3	94689	26990	75217.24149	7608.493916	82825.73541	4.22%	61.69%	23.38%
Config4	87599	23366	69585.22254	6586.886582	76172.10913	11.92%	64.77%	29.53%
Config5	91940	25979	73033.54331	7323.492532	80357.03584	7.08%	62.83%	25.66%
Config6	67040	27734	53253.95632	7818.227872	61072.18419	29.38%	71.75%	43.50%
Config7	55983	23491	44470.70758	6622.124142	51092.83173	40.92%	76.37%	52.73%
Config8	60324	26104	47919.02835	7358.730092	55277.75845	36.08%	74.43%	48.86%
Config9	62708	26990	49812.7848	7608.493916	57421.27871	33.60%	73.44%	46.88%
Config10	55617	23366	44179.97149	6586.886582	50766.85807	41.29%	76.52%	53.04%
Config11	59959	25979	47629.08662	7323.492532	54952.57915	36.45%	74.58%	49.16%

14400 Tonka Downs Drive								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	105755	36638	84007.63947	10328.26973	94335.9092	0.00%	60.00%	20.00%
Config1	93878	31653	74573.01478	8922.995848	83496.01063	11.49%	64.60%	29.19%
Config2	98449	34499	78204.03856	9725.284609	87929.32317	6.79%	62.72%	25.43%
Config3	101445	35557	80583.94389	10023.53532	90607.47921	3.95%	61.58%	23.16%
Config4	93316	31340	74126.58394	8834.760998	82961.34494	12.06%	64.82%	29.65%
Config5	97886	34186	77756.81336	9637.04976	87393.86312	7.36%	62.94%	25.89%
Config6	83772	36638	66545.20329	10328.26973	76873.47302	18.51%	67.40%	34.81%
Config7	71895	31653	57110.5786	8922.995848	66033.57445	30.00%	72.00%	44.00%
Config8	76465	34499	60740.80802	9725.284609	70466.09263	25.30%	70.12%	40.24%
Config9	79462	35557	63121.50771	10023.53532	73145.04302	22.46%	68.99%	37.97%
Config10	71332	31340	56663.3534	8834.760998	65498.1144	30.57%	72.23%	44.46%
Config11	75903	34186	60294.37718	9637.04976	69931.42694	25.87%	70.35%	40.70%

1950 West Highland Parkway								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	130717	38237	103836.4768	10779.0286	114615.5054	0.00%	60.00%	20.00%
Config1	114037	32570	90586.53664	9181.498586	99768.03523	12.95%	65.18%	30.36%
Config2	118581	35343	94196.11268	9963.208613	104159.3213	9.12%	63.65%	27.30%
Config3	118843	36292	94404.23524	10230.73217	104634.9674	8.71%	63.48%	26.97%
Config4	109458	31741	86949.15797	8947.80309	95896.96106	16.33%	66.53%	33.07%
Config5	114002	34515	90558.73401	9729.795017	100288.529	12.50%	65.00%	30.00%
Config6	103614	38237	82306.91273	10779.0286	93085.94133	18.78%	67.51%	35.03%
Config7	86935	32570	69057.76689	9181.498586	78239.26548	31.74%	72.70%	45.39%
Config8	91479	35343	72667.34293	9963.208613	82630.55154	27.91%	71.16%	42.33%
Config9	91741	36292	72875.46549	10230.73217	83106.19766	27.49%	71.00%	41.99%
Config10	82355	31741	65419.59386	8947.80309	74367.39695	35.12%	74.05%	48.09%
Config11	86899	34515	69029.1699	9729.795017	78758.96491	31.28%	72.51%	45.03%

1746 Trail Road								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	79598	21293	63229.54079	6002.50689	69232.04768	0.00%	60.00%	20.00%
Config1	75320	20154	59831.26476	5681.422245	65512.68701	5.37%	62.15%	24.30%
Config2	75228	20141	59758.18356	5677.757538	65435.9411	5.48%	62.19%	24.39%
Config3	78692	20971	62509.8498	5911.734936	68421.58473	1.17%	60.47%	20.94%
Config4	77042	20338	61199.15427	5733.291933	66932.44621	3.32%	61.33%	22.66%
Config5	76950	20325	61126.07307	5729.627227	66855.70029	3.43%	61.37%	22.75%
Config6	47486	21293	37721.02282	6002.50689	43723.52971	36.84%	74.74%	49.48%
Config7	43207	20154	34321.95242	5681.422245	40003.37467	42.22%	76.89%	53.77%
Config8	43116	20141	34249.66558	5677.757538	39927.42312	42.33%	76.93%	53.86%
Config9	46579	20971	37000.53746	5911.734936	42912.27239	38.02%	75.21%	50.41%
Config10	44929	20338	35689.84193	5733.291933	41423.13387	40.17%	76.07%	52.13%
Config11	44838	20325	35617.55509	5729.627227	41347.18232	40.28%	76.11%	52.22%

1515 Oregon Ave								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	74900	22815	59497.63318	6431.559418	65929.19259	0.00%	60.00%	20.00%
Config1	70190	21432	55756.19323	6041.691056	61797.88428	6.27%	62.51%	25.01%
Config2	70075	21415	55664.84172	6036.898748	61701.74047	6.41%	62.56%	25.13%
Config3	73905	22239	58707.24406	6269.184742	64976.4288	1.45%	60.58%	21.16%
Config4	71830	21407	57058.94514	6034.643544	63093.58868	4.30%	61.72%	23.44%
Config5	71715	21390	56967.59363	6029.851236	62997.44487	4.45%	61.78%	23.56%
Config6	49533	22815	39347.07963	6431.559418	45778.63905	30.56%	72.23%	44.45%
Config7	44824	21432	35606.43404	6041.691056	41648.12509	36.83%	74.73%	49.46%
Config8	44709	21415	35515.08253	6036.898748	41551.98128	36.97%	74.79%	49.58%
Config9	48538	22239	38556.69051	6269.184742	44825.87525	32.01%	72.80%	45.61%
Config10	46464	21407	36909.18595	6034.643544	42943.8295	34.86%	73.95%	47.89%
Config11	46349	31390	36817.83445	8848.856022	45666.69047	30.73%	72.29%	44.59%

1548 Arden Place								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	128667	39048	102208.037	11007.64989	113215.6868	0.00%	60.00%	20.00%
Config1	112543	32515	89399.76142	9165.99406	98565.75548	12.94%	65.18%	30.35%
Config2	118718	36236	94304.94012	10214.94574	104519.8859	7.68%	63.07%	26.14%
Config3	120394	37465	95636.28903	10561.40143	106197.6905	6.20%	62.48%	24.96%
Config4	109448	31941	86941.21436	9004.183185	95945.39755	15.25%	66.10%	32.20%
Config5	115622	35662	91845.5987	10053.13487	101898.7336	10.00%	64.00%	28.00%
Config6	96571	39048	76712.22875	11007.64989	87719.87864	22.52%	69.01%	38.02%
Config7	80447	32515	63903.95322	9165.99406	73069.94728	35.46%	74.18%	48.37%
Config8	86621	36236	68808.33756	10214.94574	79023.2833	30.20%	72.08%	44.16%
Config9	88298	37465	70140.48083	10561.40143	80701.88226	28.72%	71.49%	42.97%
Config10	77351	31941	61444.6118	9004.183185	70448.79498	37.77%	75.11%	50.22%
Config11	83526	35662	66349.7905	10053.13487	76402.92537	32.52%	73.01%	46.01%

296 Meadow Lane								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	57896	17620	45990.32003	4967.086432	50957.40646	0.00%	60.00%	20.00%
Config1	52276	15464	41526.01164	4359.309	45885.32064	9.95%	63.98%	27.96%
Config2	54060	16566	42943.15153	4669.963328	47613.11486	6.56%	62.63%	25.25%
Config3	58466	17559	46443.10576	4949.890503	51392.99626	-0.85%	59.66%	19.32%
Config4	54999	15829	43689.05644	4462.202675	48151.25911	5.51%	62.20%	24.41%
Config5	56784	16931	45106.99068	4772.857002	49879.84769	2.11%	60.85%	21.69%
Config6	38288	17620	30414.49104	4967.086432	35381.57747	30.57%	72.23%	44.45%
Config7	32668	15464	25950.18265	4359.309	30309.49165	40.52%	76.21%	52.42%
Config8	36606	16992	29078.37597	4790.052932	33868.4289	33.54%	73.41%	46.83%
Config9	38859	17559	30868.07113	4949.890503	35817.96163	29.71%	71.88%	43.77%
Config10	35392	15829	28114.02181	4462.202675	32576.22448	36.07%	74.43%	48.86%
Config11	37176	16931	29531.16169	4772.857002	34304.0187	32.68%	73.07%	46.14%

8104 Morgan Ave								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	87878	25599	69806.84924	7216.37035	77023.21959	0.00%	60.00%	20.00%
Config1	78525	21864	62377.19152	6163.472063	68540.66359	11.01%	64.41%	28.81%
Config2	82202	24035	65298.05664	6775.478002	72073.53464	6.43%	62.57%	25.14%
Config3	85432	24649	67863.84242	6948.564896	74812.40732	2.87%	61.15%	22.30%
Config4	79395	21608	63068.28553	6091.305541	69159.59107	10.21%	64.08%	28.17%
Config5	83073	23779	65989.945	6703.311479	72693.25648	5.62%	62.25%	24.50%
Config6	59613	25599	47354.23774	7216.37035	54570.60809	29.15%	71.66%	43.32%
Config7	50259	21864	39923.78566	6163.472063	46087.25772	40.16%	76.07%	52.13%
Config8	53937	24035	42845.44513	6775.478002	49620.92314	35.58%	74.23%	48.46%
Config9	57167	24649	45411.23092	6948.564896	52359.79581	32.02%	72.81%	45.62%
Config10	51129	21608	40614.87966	6091.305541	46706.1852	39.36%	75.74%	51.49%
Config11	54807	23779	43536.53914	6703.311479	50239.85062	34.77%	73.91%	47.82%

6104 Crescent Drive								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	119429	40227	94869.73074	11340.01055	106209.7413	0.00%	60.00%	20.00%
Config1	105241	34336	83599.33796	9679.334831	93278.67279	12.18%	64.87%	29.74%
Config2	110391	37587	87690.29671	10595.79329	98286.09	7.46%	62.98%	25.97%
Config3	113316	38837	90013.80241	10948.16889	100961.9713	4.94%	61.98%	23.95%
Config4	103525	33815	82236.21461	9532.464682	91768.67929	13.60%	65.44%	30.88%
Config5	108676	37066	86327.96773	10448.92314	96776.89087	8.88%	63.55%	27.11%
Config6	93019	40227	73890.65875	11340.01055	85230.6693	19.75%	67.90%	35.80%
Config7	78831	34336	62620.26597	9679.334831	72299.6008	31.93%	72.77%	45.54%
Config8	83981	37587	66711.22472	10595.79329	77307.01801	27.21%	70.89%	41.77%
Config9	86906	38837	69034.73042	10948.16889	79982.89931	24.69%	69.88%	39.75%
Config10	77116	33815	61257.93698	9532.464682	70790.40166	33.35%	73.34%	46.68%
Config11	82266	37066	65348.89574	10448.92314	75797.81888	28.63%	71.45%	42.91%

425 Lakeview Terrace								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	84597	29696	67200.55105	8371.316611	75571.86766	0.00%	60.00%	20.00%
Config1	75281	25441	59800.28469	7171.830075	66972.11476	11.38%	64.55%	29.10%
Config2	78698	27795	62514.61596	7835.423801	70350.03976	6.91%	62.76%	25.53%
Config3	81104	28634	64425.84834	8071.938303	72497.78665	4.07%	61.63%	23.25%
Config4	74925	25056	59517.4922	7063.298391	66580.79059	11.90%	64.76%	29.52%
Config5	78342	27410	62231.82347	7726.892117	69958.71559	7.43%	62.97%	25.94%
Config6	61686	29696	49000.94793	8371.316611	57372.26454	24.08%	69.63%	39.27%
Config7	52370	25441	41600.68157	7171.830075	48772.51164	35.46%	74.18%	48.37%
Config8	55787	27795	44315.01284	7835.423801	52150.43664	30.99%	72.40%	44.79%
Config9	58193	28634	46226.24523	8071.938303	54298.18353	28.15%	71.26%	42.52%
Config10	52104	25056	41389.38156	7063.298391	48452.67995	35.89%	74.35%	48.71%
Config11	55431	27410	44032.22035	7726.892117	51759.11247	31.51%	72.60%	45.21%

4975 Wilderness Lake								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	103000	34964	81819.17513	9856.368332	91675.54346	0.00%	60.00%	20.00%
Config1	89115	29460	70789.4737	8304.788098	79094.2618	13.72%	65.49%	30.98%
Config2	94776	32881	75286.35089	9269.169635	84555.52053	7.77%	63.11%	26.21%
Config3	96588	33568	76725.73289	9462.835264	86188.56815	5.99%	62.39%	24.79%
Config4	87371	28924	69404.10825	8153.689442	77557.79769	15.40%	66.16%	32.32%
Config5	93032	32345	73900.98544	9118.070979	83019.05642	9.44%	63.78%	27.55%
Config6	103000	34964	81819.17513	9856.368332	91675.54346	0.00%	60.00%	20.00%
Config7	89115	29460	70789.4737	8304.788098	79094.2618	13.72%	65.49%	30.98%
Config8	94776	32881	75286.35089	9269.169635	84555.52053	7.77%	63.11%	26.21%
Config9	96588	33568	76725.73289	9462.835264	86188.56815	5.99%	62.39%	24.79%
Config10	87371	28924	69404.10825	8153.689442	77557.79769	15.40%	66.16%	32.32%
Config11	94776	32881	75286.35089	9269.169635	84555.52053	7.77%	63.11%	26.21%

1068 Lombard Ave								
	Heating Load	Cooling Load	Heating (KWH)	Cooling (KWH)	Total (KWH)	%Improvement	GSHP System	Mini-Split System
Baseline	130043	40368	103301.0776	11379.75852	114680.8361	0.00%	60.00%	20.00%
Config1	108888	31940	86496.37225	9003.901285	95500.27353	16.73%	66.69%	33.38%
Config2	117246	36957	93135.64084	10418.19599	103553.8368	9.70%	63.88%	27.76%
Config3	124263	41747	98709.67145	11768.49928	110478.1707	3.66%	61.47%	22.93%
Config4	101236	30484	80417.92246	8593.454188	89011.37665	22.38%	68.95%	37.91%
Config5	114178	36898	90698.54153	10401.56386	101100.1054	11.84%	64.74%	29.47%
Config6	118922	40368	94466.98975	11379.75852	105846.7483	7.70%	63.08%	26.16%
Config7	97766	31940	77661.49005	9003.901285	86665.39134	24.43%	69.77%	39.54%
Config8	106125	36957	84301.55301	10418.19599	94719.749	17.41%	66.96%	33.92%
Config9	104279	37626	82835.16275	10606.78741	93441.95015	18.52%	67.41%	34.82%
Config10	90115	30484	71583.83463	8593.454188	80177.28882	30.09%	72.03%	44.07%
Config11	98473	35502	78223.10323	10008.03079	88231.13402	23.06%	69.23%	38.45%