DAVIS ENERGY GROUP INCORPORATED

SMUD / Truckee Donner

Geothermal Heat Pump Project

2001/2002 Monitoring Report

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Legal Notice

EXECUTIVE SUMMARY

Background and Goals

This project expands on work completed in the 1998 *SMUD/TDPUD GHP Monitoring Project Final Report – Volumes 1-3*. In the 1998 study, Davis Energy Group, Inc. was prime contractor in a monitoring and evaluation study assessing GHP system performance in the service territories of the Sacramento Municipal Utility District and the Truckee Donner Public Utility District. Fourteen systems were monitored for a minimum of one year. Monitoring results were used to calibrate detailed DOE-2 simulation models for use in projecting full-year performance relative to conventional HVAC system types.

SMUD and TDPUD received additional funding from the California Energy Commission in 2001 to complete a follow-up project. The new project would continue monitoring at the existing sites and add eight "problem" sites to the monitoring list. The "problem" sites were identified to have one or the more of the following deficiencies:

- high energy use,
- inability to maintain indoor comfort,
- insufficient heating and/or cooling capacity,
- or unreliable system operation.

The project goal was to monitor these sites, perform "whole house" diagnostic testing to determine what remediation options exist, implement viable measures, monitor further, and quantify remediation benefits. These remediation efforts defined the central focus of this study.

The following sections briefly summarize project results.

Remediation Efforts

The tight project timeline presented a significant challenge to complete all the work needed to fulfill the remediation objectives (pre-monitoring, diagnostic audits, remediation recommendations, contractor selection, remediation work, post-monitoring, evaluation and reporting). Rick Chitwood (of Chitwood Energy Management), an experienced diagnostician and HVAC/insulation contractor, performed the Truckee diagnostic audits in November 2001. Chitwood Energy Management was also able to perform the Truckee remediation work at all five sites in one week in mid-February. Cold weather continued through March 2002 in Truckee, providing good comparison data to the pre-remediation data.

SMUD diagnostic audits were completed in December 2001 with remediation recommendations developed the third week of January. Chitwood Energy Management was unavailable to perform the SMUD remediation work so alternative contractors were identified and ultimately selected. Dealing with multiple contractors, one in particular who was not responsive to the project effort, significantly slowed the remediation effort. One site was largely completed by the end of March, but by that time winter had come to an end in the Central Valley. Little useful post-remediation data were obtained for the SMUD sites.

At three of the five Truckee sites, monitoring data demonstrated a clear benefit from the remediation work. At two of the three, simple paybacks of around 20 years were projected for the measures implemented. At the third site (the highest "per ft^2" Truckee energy user), favorable paybacks of around seven years are projected. All five Truckee sites reported favorable comments regarding the remediation work in the homeowner survey. Insufficient post-remediation heating data at the SMUD sites precluded any quantification of remediation benefit. For two of the SMUD sites, summer operation will provide a good indication of the value of the remediation.

Remediation of existing sites is a costly and generally non-cost-effective exercise. In high-use areas such as Truckee, the economics will typically be more favorable since the savings potential is higher. For new construction, the economics will be much more favorable since it is much easier and less costly to install, for example, tight ducts and a tight building envelope during construction, than as a retrofit exercise. At an incremental cost of $1,800 per ton of GHP capacity, both tight ducts and a tight building envelope are clearly cost-effective for Truckee new construction. In Sacramento, both tight ducts and Low-E^2 glazing represent cost-effective new construction alternatives to added GHP capacity. Given the relatively high cost of GHP systems, it is imperative that energy efficiency be incorporated prior to the sizing and installation of the geothermal system.

Monitored Performance

Projected full-year GHP heating energy use ranged from 0.4 to 5.2 kWh/ft^2-year with average TDPUD usage approximately two and half times that of the SMUD sites. TDPUD usage varied from 1.0 to 5.2 kWh/ft^2-year (average of 3.3) and SMUD varied from 0.4 to 2.6 kWh/ft^2-year (average 1.3)

Monitored return water temperatures during full-load operation indicate a GHP advantage of 5 to 6°F vs. corresponding outdoor air temperatures. The warmer temperatures combined with the heat transfer capability of water, contributes to the higher GHP operating efficiencies. No evidence of heating season ground creep effects were observed in comparing the 1998 data with the current 2002 data. In Truckee, return water temperatures typically approach 30 °F in December and vary only a few degrees through the course of the heating season. In SMUD territory where heating system operation is less consistent on a day-to-day basis, return water temperatures reach a minimum during periods of heavy loading, but then recover quickly.

Performance Projections and GHP Economics

DOE-2 performance projections completed in the 1998 study were updated to reflect current utility rates in the SMUD and TDPUD service territories. A combination of efficient GHP performance and favorable TDPUD electric rates (compared to gas) contributed to the projected $750 annual savings for GHP vs. a standard gas furnace. SMUD savings of approximately $150 per year are projected vs. the most common conventional system alternative (gas furnace /air conditioner). In non-natural gas areas of SMUD territory, “typical” SMUD GHP customers can expect annual savings of ~$290 per year relative to an air-source heat pump. The projected savings will vary with house size and building loads, especially in SMUD territory where the three-level tiered electric rate varies from $.08 to $.16 per kWh.

Assuming a customer “10 year simple payback criteria”, GHP’s are currently viable in TDPUD service territory (ten year savings of $7,500 allows for $2,500 incremental cost per ton for a 3 ton unit). In SMUD territory, GHP’s are viable at $970 per ton incremental cost vs. air-source heat pumps (ten year savings of $2,900 divided by 3 ton system), but are not cost-effective vs. the more common furnace/air conditioner installation (ten year savings of $1,500, $500 per ton). These conclusions are sensitive to the balance between gas and electric rates.

GHP desuperheating and dedicated geothermal water heating systems were found to offer attractive economics relative to electric water heating. SMUD is better suited for these water heating technologies since both technologies provide greater benefit in areas with substantial cooling loads.

Given the higher first cost for GHP systems, every effort should be made to incorporate as much energy efficiency into a project prior to the sizing and installation of the GHP system. For the owner, this can result in reduced first costs and reduced operating costs, as well as improved comfort. For Truckee new construction, equipment sizing projections indicate that installation of tight ducts and a tight building envelope are both less costly than a larger GHP system. Similarly for Sacramento, tight ducts and high performance windows (low Solar Heat Gain Coefficient) were found to be more cost-effective than additional GHP capacity. As this project clearly showed, for retrofit applications it is considerably more difficult and costly to remedy house deficiencies that should have been properly addressed during design and construction.

Summary

GHP's, although more expensive than conventional systems to install, offer the potential for significant operating cost savings. At an incremental cost of roughly $1,800-$2,000 per ton, annual savings of $200 per ton are needed to achieve a 10 year simple payback. Areas where electric heating is common or natural gas is very expensive are prime areas for GHP market growth.

This project explored remediation efforts at a total of eight sites. Although much of the remediation work was beneficial, it is often not cost-effective due to the expense of trying to fix problems that should have been properly installed to begin with. Future GHP installations should be held to a higher construction standard (including tight ducts and building envelope, quality insulation installation, good duct design, etc) to insure that the house will perform well prior to the addition of geothermal space conditioning. High quality building envelope and HVAC system components are typically more cost-effective than additional GHP capacity. In addition, the GHP system and ground loop should be carefully sized (using industry recognized sizing tools) and commissioned to insure trouble-free operation.

Recommendations

1. SMUD and TDPUD should require the following for new GHP installations in their service territories: Manual J loads analysis, Manual D duct design, tight ducts (contractor or third-party verified), and a system commissioning report completed by the installing contractor. These steps will go a long way to insuring that installed systems meet the design intent.

2. SMUD should investigate GHP feasibility on a multi-family project, particularly if natural gas is not available. Multi-family with central water heating could offer improved economics, since year-round DHW loads will contribute to ground loop downsizing in cooling-dominated applications. A student housing project at the University of California at Davis completed in 2000 incorporates GHP water heating and space conditioning.

3. Both utilities should determine if a more favorable electric rate could be offered to GHP customers. Rising electric rates relative to gas, especially in SMUD service territory, severely hampers GHP economics.

4. SMUD and TDPUD should work with the remediation site homeowners over the next few years to gather more data on the remediation benefit. A follow-up survey in two years and utility bill analysis would be beneficial in further understanding remediation benefits.

The following two sections summarize project conclusions and recommendations from the perspective of the SMUD and TDPUD project managers.

Sacramento Municipal Utility District Conclusions and Recommendations

There are two factors pertaining to the performance of geothermal heat pumps (GHP's) that are of significant interest to SMUD: (1) the ability of GHP's to reduce summer peak-period demand for electricity; and (2) the life-cycle cost of geothermal heat pumps.

Summer Peak Load Reduction

SMUD is intensely summer peaking and technologies capable of reducing summer peak-period demand for electricity are of extreme interest. SMUD's summer peak is created by the Central Valley's infrequent and extreme maximum daily temperatures in excess of 105°F, which cause large air conditioning loads and a corresponding high demand for electricity. Peak-load benefits that can be provided by new air conditioning technologies are quite important but their benefits can be difficult to quantify. Peak-period load reduction for GHP's has been fairly well documented for short-term periods but long-term performance in the Central Valley has been undocumented. This project addresses several important issues regarding long-term summer performance.

No temperature creep was identified. While Sacramento's summer and winter space-conditioning loads are somewhat in balance, there was concern that annual average earth temperatures surrounding the loop fields might drift either upwards or downwards depending on the space-temperature preferences of the homeowners. We now have monitoring data that verifies our long-held assumption that temperature creep will not be a consideration for residential systems.

With respect to vertical helix ground loops, the monitoring data show better-than-expected performance. Three installations with performance problems were monitored. In each case, the monitoring team found a number of factors contributing to the under performance, and none of these factors were related to the size or installation of the ground-loop field. It should be noted that the ground-loop field is always blamed in when a GHP installation is not performing correctly. In SMUD's experience, the problems are usually the result of something other than the loop field. The work completed in this project verifies SMUD's prior experience. In addition, it supports other showing that vertical helix ground loops can deliver better-than-adequate heat transfer in the Central Valley.

Monitoring was performed during a fairly intense cold snap. The ground loop fields all delivered adequate heat transfer and, after outside air temperatures warmed, return water temperatures rebounded nicely. That is, typical ground-loop fields (including vertical helixes), sometimes with anti-freeze added to the water, perform well in cold snaps when sized to meet Sacramento's most extreme summertime conditions.

Improving Life Cycle Cost

The Sacramento climate is moderate with low winter heating loads and small total summer-season cooling loads. SMUD's electric rates are lower than those of California's largest electric utilities. As a result of these factors and because of the added cost associated with GHPs, life cycle costing is very important with respect to GHPs in Sacramento.

It has been observed that conventional residential HVAC units are often somewhat oversized. This sizing strategy automatically compensates for any problems that may found in the air distribution system and building shell. GHP's, because of their increased expense, are less apt to be oversized. As a result, problems with the air distribution system and building shell are more likely to create a situation where the geothermal heat pump appears to be under-performing. The whole-house approach used in this project demonstrates the need for a commissioning/whole-house component in any geothermal heat pump program. Careful design review and construction inspection would have yielded GHP installations with better performance.

Based on the results of this project, it is clear that any geothermal heat pump program should have a commissioning component or be closely linked to a commissioning program. If SMUD adopts a fully operational geothermal heat pump program, it will be strongly recommended that a whole-house approach be included as part of the program. This should include commissioning, monitoring and remediation recommendations.

The cost of the ground loop field has been identified as the single most important factor in the high cost of geothermal pump installations. In an effort to reduce the cost of GHP's, SMUD has pioneered the use of vertical helix ground loop fields. This technology is ideally suited to California's Central Valley which rests on thousands of feet of sedimentary material with very little rock. Theoretical calculations (cost of pipe, the cost of augering, etc suggest that vertical helixes should be considerably less expensive than deep-bore ground loops. To date, this has not been the case but we continue to believe that, given widespread implementation, the cost could be much lower. The monitoring work completed in this project validates the assumption that vertical helixes can deliver excellent long-term heat transfer. In addition, the monitoring suggests that there are no problems occurring in the vertical helix ground loop fields.

An important, but perhaps understated, result of this work is the indication that a whole-house approach to the design and construction of homes with GHP's would result in structures with smaller heating and cooling loads and smaller GHP's. A smaller GHP will be less expensive and financially more attractive to the homeowner or homebuyer.

The project suggests that desuperheating offers attractive economics and it should be included as a component in a future SMUD GHP program.

With respect to long-term performance, this project shows that the efficiencies of GHP installations in Sacramento are not deteriorating over time. This is important because it shows that there are no long-term performance issues likely to bedevil an operational GHP program.

Truckee Donner Public Utility District Conclusions and Recommendations

The California Energy Commission grant-funded TDPUD/SMUD geothermal heat pump and whole-house weatherization research data collection ended mid-April, 2002. I was very pleased after reviewing the report being compiled by Davis Energy Group. My write-up here will address the research findings that came out of the Truckee portion of the project. This report includes discussions on both the 1996-98 as well as the 2001-02 research, as the earlier research was important in determining the need for the later.

The CEC funded geothermal research that was done in 1996 to 1998 focused on the performance of the geothermal heat pump systems in the study. Two of the significant findings in the study were that the heat pump units varied moderately in their coefficient of performance (COP) from “least” efficient to “most” efficient. More dramatic was the variability in energy usage from site to site. This is very helpful in showing how significant site conditions are to the economic benefit high efficiency heating brings to the building occupant/owner who is responsible for paying the energy bills.

There are two types of site conditions that affect the cost of heating a building. One is the external site conditions where the building owner has little or no ability to affect. This would include such factors as weather conditions affecting outside air temperature, etc. and shading caused by other buildings, trees or other objects. Each site has its own micro-climatic conditions affecting the heating requirements of a building, therefore the cost to heat. The other major site factor is the building itself. The common issues with buildings affecting the cost of heating include: floor, wall and ceiling insulation levels, single vs. double-pane windows, air leakage in the building envelope, distribution system design and distribution system air leakage issues. These are all factors that the building user and bill payer can improve.

After the 1996-98 CEC funded geothermal heat pump research project it was evident that some sites were not performing very well even though their heat pump units were operating fine. There were also other sites in Truckee where homeowners had high energy bills in their geothermal heat pump heated homes. It did not make sense to have a super high efficiency heating system causing high energy bills. It became evident that we must look into making the building and distribution system more energy efficient so that the heat pump could perform as expected and provide low energy bills to the user. The bottom line is it does not make sense to put a high efficiency heating system into a low efficiency building.

After the 1996-98 study, TDPUD did start promoting the “House as a System” approach with all future geothermal heat pump installations. The idea was to first make the building as cost-effectively energy-efficient as possible. This would then bring the sizing of a heating system down. In many cases we were able to reduce the heating tonnage requirement down by about one ton or 12,000 Btu/hour. This would save about $4,000 for the cost of a geothermal heat pump installation and also reduce the cost of heating the building each winter. This could all be done for an average conservation investment of about $1,500 to $2,000 per site. The question then became what really are the economics of doing this? This is when SMUD and TDPUD decided to approach CEC staff to do the 2001-02 study.

TDPUD and SMUD received the go-ahead to do this study in the Fall of 2001. The sites were set up for monitoring and the “House as a System” work was performed midway through the monitoring. Each of the five Truckee sites had remediation work of between $2,000 and $3,000. In some cases the economics of the remediation work was very good and in other cases the economics were marginal. One issue we should note is that all five Truckee sites bordered on extreme in that some were non-operational prior to the study. The Truckee project manager believes that these were the “worst” under-performing geothermal heat pump sites out of about 50 in Truckee. So not only did they require efficiency work, but they required other remediation work to bring them to a standard operational mode. Also, in some cases efficiency work had already been performed on some of these sites reducing the calculated benefit efficiency would have provided these projects had all the efficiency work been performed during remediation and monitoring, not prior to.

It may be that these under-performing sites would have shown even better economics if only the basic, most cost-effective remediation work had to be performed on them. If any sites had un-insulated attic spaces they would have shown great improvement. Only one site was practical for adding additional insulation. It was already insulated, but could use a little extra. All sites required reduction in building envelope infiltration. Most sites required a reduction in central air distribution system or duct leakage. The building and duct infiltration leakage reduction is generally cost-effective. Most sites received a vapor barrier on the dirt crawl space floor. That is a helpful measure, but is not one of the more cost-effective measures. The economics could have also been improved if the building owners/managers had been able to perform some of the work with their own maintenance staff or themselves. With some measures this can be done while others require contractor equipment and expertise. Overall, the project was successful. All five sites are operating efficiently and the users are very appreciative. TDPUD staff has documented the remediation work with photos, also available on disc.

Since the last research was done from 1996-98 Truckee Donner Public Utility District put together cash incentives to encourage homeowners and businesses to perform “House as a System” measures. TDPUD, first of all, provides a $100 rebate for just having one’s home or business checked for insulation levels and tested for building and duct air leakage. The idea is to get a survey of the “problem”. TDPUD also provides a 10% rebate on the cost of the building efficiency measures including installation up to a total rebate of $500. Since the results of this current 2001-2002 research study, TDPUD staff is even more convinced of the value of applying conservation first. TDPUD plans on putting greater emphasis to building users on the need to make their buildings as economically efficient as possible, then pay for and install the more expensive higher efficiency heating systems like geothermal heat pumps. It is worthwhile because of the savings on the capital cost of buying the system is reduced by about $4,000 and the future reduction in the building’s operational energy costs.

Heating contractors have a lot to gain from approaching their building heating jobs from the “House as a System” approach. When heating contractors are sizing the heating equipment for a building they need to determine the buildings hourly heat loss using information about the efficiency of the building envelope at some specified design temperature. They typically bring together good data about r-values on the building materials, but do not have an accurate way to determine the heat loss caused by a leaky building envelope and/or central air distribution system. The “House as a System” analysis can provide those numbers and show where important efficiency improvements can be made in a building. Heating contractors who improperly size heating systems for a building will run into problems heating the building and have several return trips before they solve the problem. They may solve the problem by putting in a larger heating system at their expense whereas they could have solved the problem by reducing the building's heating requirement through the "House as a System" approach. Efficiency reduces equipment capital cost requirements, reduces the energy costs associated with heating the building and may save a contractor considerable time, money and problems.

TDPUD will continue to offer cash incentives and encourage "House as a System" measures to our utility customers. TDPUD will expand their education and marketing emphasis of the value of this work. TDPUD staff spoke recently to a contractor who is planning to offer low-cost energy surveys to evaluate for "House as a System" opportunities. The contractor will be offering this service in Truckee by this summer. TDPUD staff is currently working with several northern California utilities to help them understand what goes into developing a GSHP program for their customers. TDPUD appreciates the funding for the project by the CEC and would like to help the CEC promote this work statewide as can be done practically.

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1. Overview

1.1. Background

Geothermal (or "ground source") heat pumps (GHP's) generally utilize a buried "loop" of tubing to exchange heat with the soil, rather than the refrigerant-to-air heat exchangers used by conventional air-source heat pumps (ASHP's). GHP's typically have higher operating efficiencies than ASHP's due to milder condensing and evaporating temperatures, elimination of defrost cycles, little or no need for supplemental resistance heating during cold weather, and the use of desuperheaters to heat domestic hot water. Since GHP systems lack the outdoor compressor/fan unit they are also quieter than ASHP's. GHP systems are more common in the north-central and southern states, but have not achieved widespread popularity in the West. The primary barrier to GHP's in California is due to cost: higher first costs to install the systems, and relatively high electric rates which reduce GHP savings potential when compared to the typical gas furnace/air conditioner HVAC system.

To verify GHP market viability, the Sacramento Municipal Utility District (SMUD) and the Truckee Donner Public Utility District (TDPUD) originally contracted with the California Energy Commission (Commission) to conduct a field-monitoring project in 1996. Both SMUD and TDPUD have pioneered GHP market development in California by providing direct incentive payments, organizing bulk purchase programs, and facilitating infrastructure development. Utility and Commission interest in GHP technology stems from the potentially lower peak demand and reduced energy use offered by GHP systems. Davis Energy Group, the prime contractor on this project, completed a detailed monitoring and evaluation assessment in the 1998 project report entitled "*SMUD/TDPUD GHP Monitoring Project Final Report – Volumes 1-3*".

In 2001, SMUD and TDPUD received additional funding from the Commission's Geothermal Program to further study GHP's. The primary focus of the new work was twofold: to identify, monitor, and remediate "problem" GHP sites, and to gather additional long-term monitoring data.

1.2. Description Of Utility Service Areas

SMUD is an electric utility serving customers in Sacramento County. The utility is summer peaking with residential air conditioning a primary contributor to the peak load of 2,250 MW. Summers are typically hot and dry with temperatures exceeding 100°F about 20 times a year. Winters are relatively mild with low temperatures rarely falling below freezing. SMUD peak winter system demand is about 1,550 MW. Natural gas is available in most of SMUD's service territory making gas furnace and split system air conditioners the most common residential system.

Homes built during the 70's and 80's, when SMUD was promoting air source heat pumps, and homes in rural areas of the county have a higher saturation of heat pumps or electric resistance systems. SMUD is committed to advanced and renewable technologies and is presently leading the other California utilities in developing geothermal heat pump technologies and building a local contracting infrastructure. Geothermal heat pumps are a promising technology for SMUD and for Sacramento, particularly in outlying areas with no natural gas service. They will provide substantial energy and demand savings for participating customers, reduced utility bills, and environmental benefits including reduction of greenhouse gas emissions and reduced noise pollution. In addition, the technology can serve as a vehicle for customer retention and develop the infrastructure for new business ventures.

TDPUD is an electric and water utility serving about 13,000 customers in the Sierra Nevada, approximately 30 miles from Reno, Nevada. At an elevation of 6,000 feet, the area has cold winters with a winter peak utility load of about 28 MW. Nighttime temperatures below 0°F are not uncommon[1], although winter days are generally sunny. Summers are mild and dry with few days exceeding 90°F (summer peak load is about 18 MW). With the appearance of natural gas in the urban and suburban areas in the later 1990's, natural gas forced air heating now competes with propane, electric heat and wood stove heating. Unstable pricing of propane, and damage to propane lines from heavy snow loads discourage use of this fuel. Natural gas prices, which are burdened with the cost of pipeline development, and the high cost of electric resistance heating make GHP an attractive alternative. Wood stoves, often used as a primary heat source, substantially compromise the winter air quality of the Truckee area. Geothermal heat pumps are a promising technology in mountain areas like Truckee, where inexpensive natural gas is unavailable.

The combination of high cost of competing fuels, cold winters, and air quality concerns make the TDPUD service area prime for GHP market development. To promote GHP technology TDPUD has sponsored events bringing together heat pump manufacturers, heating contractors, drillers, lending institutions, homeowners, and other GHP candidates.

2. Objectives

In 2001, the Commission's Geothermal Program allocated additional funding to SMUD and TDPUD to further advance the prior research efforts. A primary objective for the 2001/2002 project was to:

- Identify "problem" GHP sites in each service territory
- Monitor system performance at these sites (pre-monitoring)
- Perform diagnostic work to identify potential remediation work
- Perform remediation work
- Monitor system performance (post-monitoring)
- Analyze pre- and post-monitoring data and report results
- Survey the homeowners on their perceptions regarding the benefits of the remediation
- Develop more detailed case studies on three of the sites

Additional project objectives included:

- Collect additional performance data from the sites monitored in 1996-1998 and compare energy use and ground loop performance
- Update GHP economic projects developed in the 1998 report including overall GHP cost-effectiveness, GHP desuperheating, and dedicated GHP water heating

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[1] Winter 0.6% design temperature equal to 0°F (from *Climatic Data for Region X – Arizona, California, Hawaii, Nevada*, ASHRAE, 1982). This design temperature indicates that 0.6% of the winter hours are colder than 0°F.

- Document system performance under peak winter operating conditions
- Evaluate the economics of implementing building improvements vs. adding GHP capacity
- Evaluate the cost and performance of shallow vertical helix ground loops

3. Methodology

3.1. Monitoring Plan

The project work plan specified recommissioning the 14 existing sites from the 1998 GHP study and the addition of 10 new monitoring sites (with up to two multiple GHP system sites). Three of the 14 existing SMUD sites declined to participate in the ongoing monitoring for various reasons[2]. This loss of existing sites was offset by the fact that of the nine new sites four had two heat pumps each and one had three (resulting in a total of 20 sites and 27 heat pumps). See Table 1 in section 3.2 for a summary of site characteristics of both new and existing sites.

A general monitoring plan was developed to describe the monitoring approach applied to all sites. The general plan identified monitoring objectives, strategy, and methods. The general plan also specified hardware and data acquisition procedures, and listed algorithms to be used in programming the remote site dataloggers.

In addition, specific monitoring plans were developed for each site based on information collected during site audits. Specific plans listed site information such as equipment location and ground loop type, and included data point lists, drawings showing sensor locations, datalogger panel wiring diagrams, and cable lists. Both the general and specific monitoring plans were delivered to the Project management team.

Monitoring at all sites allowed for continuous collection of the following data:

1. Indoor temperature
2. Outdoor temperature
3. Supply and return air temperature (forced air GHP systems)
4. Supply and return water temperature (hydronic water-to-water systems)
5. Total GHP energy use and GHP auxiliary heat energy use (if installed)
6. Ground loop supply and return water temperatures

Airflow rates were determined at the new sites using one-time powered flow hood measurements and "new" loop flow rates were estimated based on one-time pressure differential reading (across the GHP unit's refrigerant-to-water heat exchanger). Existing sites in Sacramento typically had in-line ground loop flow meters from the prior monitoring, allowing for continuous loop flow data collection. Most of these sensors had been removed in the Truckee sites due to leakage problems since the 1998 study.

All sensors were scanned at 15-second intervals with data averaged/totaled and logged at 15-minute intervals. Using the programming features of the datalogger, energy transfers between the heat pump and the ground loop, and between the heat pump and the house were computed from mass flow rates and temperature differences.

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[2] Two of the sites had been recently sold and the owners were not interested in continuing monitoring the third site declined to participate due to personal reasons.

3.2. Monitoring System Installation & Commissioning

Table 1 provides a brief description of the monitoring sites and the installed GHP systems and ground loop descriptions. “Existing (R)” systems represent installations where significant portions of the monitoring installation had been removed and needed to be reinstalled. Three of the sites were non-residential buildings (sites T5, T10, and S2). Two of the sites (T2 and T10) were hydronic systems where a water-to-water GHP system heated a storage tank delivering water to a radiant floor heating system. Appendix A contains site audit forms from each site which further document the installations.

DEG developed detailed specifications of required hardware necessary for the 9 new monitoring sites (see General Monitoring Plan in Appendix B). SMUD loaned much of the monitoring hardware (data loggers, modems, and power monitors for the original installations, and data loggers for the new installations) and the remaining equipment was purchased or leased through available project hardware funds. All hardware was procured by November 2001, and DEG then pre-assembled 2’ x 4’ electrical panels containing dataloggers, modems, and low-voltage power supplies to facilitate field installation. From mid-November to early January DEG installed the monitoring systems at the new sites and reinstalled and commissioned monitoring equipment at the existing sites. On average it took approximately two person-days per site to install and commission monitoring systems.

Table 1: Description of GHP Monitoring Installation Sites

Site	Monitoring Status	Construction Type	Floor Area (ft^2)	Nominal GHP tons	Ground loop type: Vert Bore (ft/ton)	Ground loop type: Vert Helix (# × depth)
T1	Existing	Retrofit	2500	4	200	-
T2	Existing (R)	New (Hyd)	3500	5	180	-
T3	Existing (R)	Retrofit	1230	3	160	-
T4	Existing (R)	Retrofit	1250	3.5	114	-
T5	Existing	Retrofit (Bed & Breakfast Inn)	3580	5 + 3	150	-
T6	New	Retrofit	1400	3	-	4 × 30’
T7	New	Retrofit	1625	2 + 3.5	150, 137	-
T8	New	Retrofit	1650	3	150	-
T9	New	Retrofit	2050	4.5	170	-
T10	New	New (Hyd) Commercial	3450	5 + 5	240	-
S1	Existing	New	2910	5	200	-
S2	Existing	Retrofit (office)	550	2.5	200	-
S6	Existing	New	2540	5	200	-
S7	Existing	Retrofit	2620	4	-	5 × 20’
S8	Existing	Retrofit	2400	5	240	-
S9	Existing	New	1260	3	133	-
S10	New	Retrofit	3650	4 + 5	-	5 × 60’
S11	New	Retrofit	4975	2 +3 +4.5	-	7 × 60’
S12	New	New	4050	3 + 4	-	8 × 30’
S13	New	Retrofit	1300	3	-	4 × 35’

After completion of the monitoring installation and verification of phone line connections (for data downloading), DEG visited each site to troubleshoot and commission the monitoring systems, and finalize datalogger programming. The first nine Truckee sites were commissioned by early December 2001. The commissioning of the last site (T10) was delayed until February 2002 as the construction schedule delayed completion of this small commercial building. The existing SMUD sites were commissioned by late December 2001 and the new SMUD sites were commissioned by early January 2002.

3.3. Data Collection

Routine data acquisition commenced as soon as each site was commissioned. DEG developed a communications software script program to sequentially dial each active site and prompt the datalogger to download stored data. A host computer in the DEG office downloaded the 15 minute logged data on a nightly basis. Data were promptly reviewed to identify out-of-range readings resulting from power outages or failed sensors. On a weekly basis data were also visually reviewed to provide a second verification of data quality. Occasionally, voltage spikes or other problems would result in modem or sensor failures that were identified by these data reviews. Resetting or replacing modems, or fixing or replacing the faulty sensor resolved these failures.

DEG compiled monthly site data summaries at the end of each month which included a summary sheet and weekly graphs of indoor, outdoor, and loop return temperature and heat pump energy (see example site summary report in Appendix C). These summaries were included in the monthly progress report submitted to the CEC, SMUD and TDPUD.

3.4. Remediation Evaluation

Eight houses[3], five in Truckee and three in Sacramento, were targeted for "whole house performance" audits[4]. These audits explored the contributions to "whole house" performance of heat pump performance, building envelope deficiencies, HVAC system airflow, air distribution system leakage, system controls, and occupant interaction with HVAC controls. A "whole house" assessment is valuable for any house, but especially so for houses with advanced technologies such as geothermal heat pumps. If remediation, or for new houses the addition of energy efficiency measures, can be cost-effectively implemented, the GHP system can be downsized saving first cost and operating costs.

The utility project managers identified these sites as those most in need of remediation. A diagnostic evaluation report, included in Appendix D, was developed for use in identifying and documenting performance issues. Subcontractors Rick Chitwood of Chitwood Energy Management and Alan Amaro performed the diagnostic audits. Chitwood, as well as being a licensed contractor, has extensive experience in performing diagnostic "whole house" evaluations of new and existing homes throughout California.

After completion of the audits, a list of recommendations was developed for each site. Appendix E lists the remediation recommendations for the sites, as well as recommendations that were not

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[3] with a total of 13 GHP systems

[4] The ninth new house did not have a diagnostic audit completed, since their complaints were limited to insufficient airflow (and resulting comfort) in one bedroom. This was easily remediated by replaced a kinked and undersized supply duct with a larger, properly installed duct.

implemented for cost or other reasons. Under the direction of the SMUD and TDPUD project managers, the project remediation budget was allocated among the various sites with priority given to measures projected to have the greatest impact.

Several outside contractors were hired to complete the remediation work, including Chitwood Energy Management, Energy Solutions Group, Performance Energy, Five Star Performance Insulation, and Perfection Home Systems. The scope of the remediation efforts involved:

- Increasing insulation levels (ceiling, kneewalls)
- Infiltration mitigation (caulking, sealing of envelope penetrations, etc.)
- Duct sealing (to reduce duct leakage and increase airflow to conditioned space)
- Improvement of the thermal envelope (crawlspace sealing in Truckee to reduce floor losses)
- Installation of depressurized flow centers (to mitigate ground loops which had been leaking)
- Replacement of restrictive supply/return grilles with efficient ones (reduce pressure drop)
- Addition (or upsizing) of supply and return ducts (to increase HVAC airflow)
- Installation of whole house fans (performed at one Sacramento site as a potential solution to mitigate system undersizing for one of the two GHP units)

The audits were performed in Truckee in mid-November, and the remediation work was performed in mid-February. The audits for the SMUD sites were performed in mid-December and the remediation work was completed in late March and April.

3.5. Data Analysis Approach

3.5.1. Monitoring Data

Monitoring data collected during the current project were used for the following:

- To assess the impact of remediation efforts on GHP system energy use
- To document ground loop performance and compare with 1998 data to assess creep issues
- To document peak winter day performance of the installed systems
- To document heating energy use at the monitoring sites

The following sections describe how the collected data were used.

3.5.2. Remediation Sites

The primary project goal for the remediation task was to identify and implement preferred remediation measures, quantify the energy savings, and estimate the cost-effectiveness of the remediation work. For each site, a minimum of 60 days of winter monitoring occurred prior to the remediation work. This data characterized base case energy consumption. For the Truckee, sites 45-60 days of post-remediation data were available for comparison. Sacramento remediation work was more problematic due to difficulty in finding and scheduling qualified contractors with experience in implementing efficiency recommendations beyond their narrow focus. One Sacramento-area HVAC contractor who performed site inspections could not be convinced that the proposed work identified in the remediation audits would be beneficial [5]. Since remediation work was not completed earlier than late March, little useful post-remediation data were available for comparison to the pre-remediation data.

To quantify the remediation benefit at each site, the following approach was developed. First, daily GHP energy use (including GHP auxiliary electric heat) was calculated. In addition, daily average "indoor-to-outdoor temperature" difference was calculated. Colder days were anticipated to have higher usage than milder days [6]. Regression relationships were then developed relating daily energy consumption as function of the average indoor-to-outdoor temperature difference. A similar process was completed for post-remediation data resulting in two regression lines per site (pre and post).

Since project monitoring did not encompass a full heating season, the partial year pre- and post-regression relationships were used in junction with an hourly DOE-2 weather file. An Ely, Nevada DOE-2 TMY weather file (identified in the 1998 monitoring study as most representative of Truckee weather) was used with a constant 68 °F indoor temperature to calculate the daily average indoor-to-outdoor temperature difference. The regression relationships were then applied to calculate daily pre- and post-remediation usage. The savings were totaled, dollar savings were computed, and simple paybacks were calculated based on the projected annual savings and the actual remediation costs.

Case studies, included in Appendix F, were developed for three of the sites to document in more detail the remediation activities.

3.5.3. DOE-2 Modeling Assumptions

The 1998 study assessed GHP economics in both SMUD and TDPUD service territories by completing a detailed DOE-2 modeling study of GHP and conventional system performance. The 1998 evaluation used monitoring data to calibrate the DOE-2 ground loop model and provide performance assumptions for GHP system modeling. The primary focus of the 2002 study was on remediation work to improve whole house performance, limiting the modeling evaluation effort to updating the prior economics based on utility rate changes. The 1998 report contains detail on the modeling assumptions related to building characteristics, thermostat set points, ground loop modeling, etc. The following discussion documents the assumptions used in the DOE-2 modeling.

Based on input from the SMUD/TDPUD project managers, a matrix of simulation cases was developed. For both utilities, cases were run for new and retrofit residential construction. "Typical" and "High" load cases were developed on a 1,700 ft^2 prototype to assess the sensitivity of results to variations in building load. Parametric evaluations were used to assess the impact of monitored variations in GHP and ground loop performance on results. To achieve this, worst and best case performance scenarios were developed. The "worst" case combined poor ground loop performance with poor heat pump performance. The "best" case scenario combined "best case" ground loop performance with "best case" heat pump performance.

[5] After repeated efforts to get the HVAC contractor to provide a quote on the required work, we contacted another firm (Performance Energy), who although not a mechanical contractor was able to clearly understand the issues that needed to be addressed to improve whole house performance.
[6] This was generally the case, although several Truckee sites used wood stoves or gas appliances as supplemental heat sources, complicating the task of quantifying the remediation benefit.

The most common conventional heating system in the Truckee area is a natural gas or propane furnace. Base case analyses were performed for both standard efficiency gas furnaces (78% AFUE) and high efficiency condensing furnaces (92% AFUE). Since horizontal ground loops are uncommon in the Truckee area, all TDPUD DOE-2 simulations assumed vertical ground loops.

In SMUD service territory, base case systems are typically 78% AFUE gas furnaces with 10 SEER air conditioners (Gas/AC), however air-source heat pumps (ASHP's) are also common in the retrofit market and in more rural areas of SMUD territory where natural gas in not available. Both new and retrofit cases used the same equipment efficiencies (10 SEER, 78% AFUE) with the retrofit case assuming that equipment replacement is needed and performance impacts should therefore be compared to the conventional base case system alternative. Three separate base case system types were simulated for SMUD:

- Standard Gas/AC case (78% AFUE furnace/10 SEER AC)
- High efficiency cooling Gas/AC case (78% AFUE furnace/12 SEER AC)
- Standard ASHP case (6.8 HSPF/10 SEER ASHP)

Typical, best, and worst case GHP scenarios were run with the vertical ground loop configuration. Table 2 summarizes the modelling cases evaluated and Table 3 summarizes the nominal GHP equipment efficiencies (ARI-330 ratings) used in the modelling study.

Table 2: DOE-2 Modelling Cases

TDPUD Cases				
	House Type	Building Loads	GHP	Ground Loop
Gas – 78% AFUE	New, Retrofit	M, H	n/a	n/a
Gas - 92% AFUE	New	M	n/a	n/a
GHP (Vertical loop)	New	M	W, T, B	W, T, B
"	New	H	T	T
"	Retrofit	M, H	T	T
SMUD Cases				
Gas/AC – 10 SEER	New, Retrofit	M, H	n/a	n/a
Gas/AC – 12 SEER	New	M	n/a	n/a
ASHP - 6.8 HSPF	New, Retrofit	M	n/a	n/a
GHP (Vertical loop)	New	M	W, T, B	W, T, B
"	New	H	T	T
"	Retrofit	M, H	T	T
GHP (Horizontal loop)	New, Retrofit	M, H	T	T

Note: For loads, "M" = medium, "H" = high
For GHP and ground loop, "W" = worst, "T" = typical, "B" = best

Table 3: Nominal GHP Efficiency Inputs

	ARI-330 Efficiencies	
Site	Heating COP	Cooling EER
Typical	3.1	13.4
Best	3.3	15.7
Worst	3.0	10.9

Average utility rates used in calculating annual costs were:

- SMUD electric rate of $.105/kWh[7]
- PG&E gas rate of $.70 per therm (PG&E provides gas service in SMUD service territory)
- TDPUD electric rate of $.10/kWh
- Truckee area Southwest Gas rate of $1.39 per therm[8]

3.5.4. Desuperheater and Dedicated GHP Water Heater Evaluation

GHP technology offers two options for domestic water heating: desuperheaters and dedicated GHP water heating (DGWH). A desuperheater is a refrigerant-to-water heat exchanger located on the discharge side of the compressor. The heat exchanger extracts heat from the high temperature refrigerant exiting the compressor. A small pump circulates potable water between the water heater (or pre-heat storage tank) and the heat exchanger. A DGWH is 1 to 1.5 ton water-to-water GHP system providing high efficiency heat pump water heating. The primary difference between the desuperheater and the DGWH is that the desuperheater only provides heat when the GHP unit is operating in space conditioning mode; the DGWH heats water independently of space conditioning operation.

Both one- and two-tank desuperheater systems are shown in Figure 1. Although the one-tank configuration is less costly to install, the two-tank approach provides greater desuperheater contribution to total domestic hot water (DHW) loads. The pre-heat tank temperature increases when the GHP system operates and decreases during DHW draws, as supply hot water is replenished through the partially tempered pre-heat tank. The more the GHP system operates, the greater the desuperheater contribution. A one-tank system is severely constrained by the water heater set point; for example, if the tank set point is 135°F, the desuperheater's ability to heat water is reduced due to the high inlet water temperatures entering the heat exchanger.

Desuperheaters are most effective during cooling operation when the reclaimed heat is essentially "free" heat. Since the desuperheater will result in less heat rejection to the ground loop, cooler ground loop temperatures will result in improved system performance. During heating operation, the desuperheater increases overall system performance (due to effectively increasing the size of the condenser heat exchanger), but also reduces the rate at which heat is supplied to the house. To supply the same amount of heating energy to the house, a GHP with desuperheater must operate slightly longer. Given these performance considerations, a desuperheater will be most cost-effective under the following conditions:

- High loads (especially cooling)
- Two-tank system
- High DHW loads
- High energy cost for supplemental DHW fuel

[7] SMUD's current tiered residential rates (Schedule R) range from $0.079/kWh (low tier), to $.135 (mid tier), to $.162 (high tier). An average rate of $.105/kWh was used for this study. Usage variations will affect the incremental rate and resulting annual cost.

[8] Southwest Gas provides gas service to the Truckee area. Rates are high relative to PG&E, partly to cover the expense of bringing natural gas to the area approximately five years ago. The $1.39 per therm rate was based on monthly first and second tier gas rates during 2001, weighted by typical monthly usage. 2001 was a volatile year during which Southwest Gas rates changed eleven times.

All desuperheater evaluations presented in this report are based on a two-tank configuration, since the economic viability of one-tank systems is less favorable. A $780 installed cost was estimated for two-tank systems, and assumes the DHW tank is in close proximity to the GHP unit. In the 1998 study, desuperheater performance was monitored at a total of four sites (sites S1, S6, T1 and T3). This study updates the 1998 savings projections based on current utility rates.

Figure 1: Schematic of One- and Two-Tank Desuperheater Systems

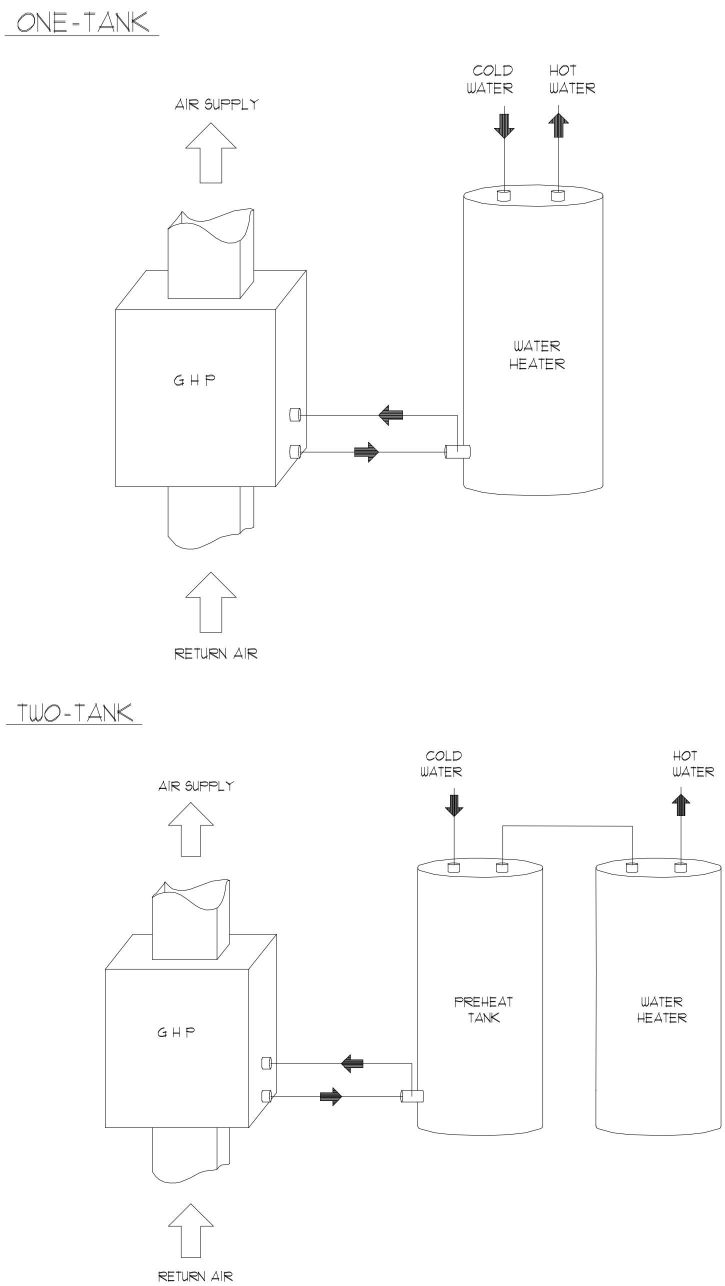
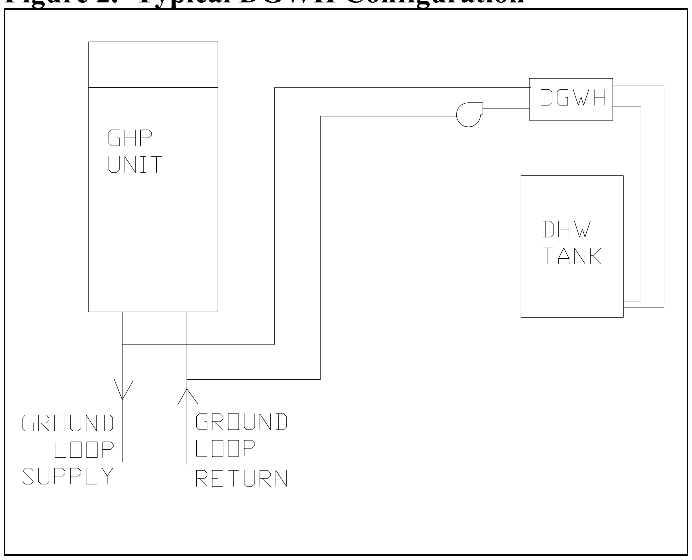


Figure 2 shows the typical DGWH configuration. The DGWH usually shares a ground loop with the space conditioning geothermal unit. If the DHW tank thermostat calls for water heating, the ground loop circulating pump and DGWH unit are energized and the unit operates until the temperature has reached set point. DGWH units are most beneficial in areas where cooling space-conditioning loads determine the ground loop sizing. In these situations, summer water heating operating reduces the amount of heat rejected to the ground loop, potentially allowing for a reduction in ground loop sizing and a reduced GHP system installed cost. This technology is fairly new to California. For this study a $2,000 incremental cost was assumed for a DGWH.

A DGWH was monitored and evaluated in detail in 1998 during the course of PG&E's Geothermal Heat Pump Demonstration Project[9]. Performance projections from the 1999 PG&E study were updated based on the current SMUD and TDPUD area utility rates.

Figure 2: Typical DGWH Configuration



4. Results

Appendix G contains excerpts from the data collected, including monthly available monitoring data by site, monthly average GHP operating fraction, energy use breakdown, loop return water temperatures, and peak winter day performance plots for each site.

Results reported in this section include a summary of monitored field data, results from the remediation tasks, updated GHP cost-effectiveness results, desuperheater/DGWH performance projections, and a cost-effectiveness evaluation of energy efficiency measures vs. additional GHP capacity.

4.1. Monitoring Data Summary

[9] See Davis Energy Group's *Evaluation of Ground-Coupled Heat Pump Water Heating Options in Pacific Gas and Electric Service Territory*, May 1999.

4.1.1. Heating Energy Use

The review of monitoring data for the 20 sites revealed a wide range of space conditioning operating profiles, usage patterns, microclimates & building design (particularly in Truckee [10]), and thermostat control patterns. In addition, supplemental heating sources such as wood stoves and fireplaces were used at some sites. Auxiliary resistance space heating was observed at the following sites: T1, T7, T8, T9, S1 and S6. Site auxiliary energy usage can be seen in Appendix G in the "Monitored Energy Use Breakdown" table.

Table 4 presents total GHP space conditioning energy use, including pump and auxiliary heating energy use, for the time period listed in the second column Since the monitoring period did not cover the entire heating season, full year heating energy consumption was extrapolated using the estimated monthly heating loads calculated by DOE-2 for the two regions [11].

Table 4: Heating Energy Use Summary

Site	2002 Data Period	1998 Monitoring Study: Monitored[1] Heating (kWh)	1998 Monitoring Study: Normalized (kWh/ft^2 per year)	2002 Monitoring Study: Monitored[1] Heating (kWh)	2002 Monitoring Study: Full Year Extrapol-ation	2002 Monitoring Study: Normalized (kWh/ft^2 per year)
T1	Dec-Mar	17037	6.8	6062	8786	3.5
T2	Dec-Mar	5334	1.5	8324	1203	3.4
T3	Dec-Mar	3659	3.0	3174	4600	3.7
T4	Dec-Mar	5387	4.3	1797	2605	2.1
T5	Dec-Mar	8592	2.4	4893	7091	2.0
T6	Dec-Mar	-	-	3436	4980	3.6
T7	Dec-Mar	-	-	3509	6986	4.3
T8	Dec-Mar	-	-	1084	1571	1.0
T9	Dec-Mar	-	-	7355	10659	5.2
T10	Feb-Mar	-	-	4098(3)	15763(3)	4.6
S1	Jan-Mar	787	0.3	1183	2191	0.8
S2	Jan-Mar	785	1.4	193	358	0.7
S6	Jan-Mar	3386	1.3	3563	6598	2.6
S7	Jan-Mar	1943	1.3	1219	2257	0.9
S8	Jan-Mar	3321	1.4	994	1841	0.8
S9	Jan-Mar	189(2)	0.2	270	501	0.4
S10	Jan-Mar	-	-	3513	6506	1.8
S11	Jan-Mar	-	-	2843	5264	1.1
S12	Jan-Mar	-	-	4503	8339	2.1
S13	Jan-Mar	-	-	1128	2088	1.6

Notes: (1) For months with partial data, energy use was calculated as *monitored use / available data fraction*
(2) No data available Dec '97
(3) Missing data for Dec and Jan, GHPs were not yet commissioned due to construction delays.

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[10] Building design including passive solar features and solar access are key factors affecting heating usage in Truckee.

[11] DOE-2 simulations indicate that the December through March period typically represents 69% of the annual heating load; therefore measured usage for sites with Dec-March data were divided by 0.69 to arrive at an annual usage estimate. Likewise site T10 (with only February and March data), annual usage was determined by dividing monitored use by 0.26, and a 0.54 factor was used for SMUD sites (Jan-Mar).

Truckee site heating usage varied from a low of 1.0 kWh/ft ^{2}-year (site T8) to a high of 5.2 kWh/ft^2-year (site T9), with an average of 3.3 kWh/ft ^{2}-year. Variations in usage were due to a variety of factors including microclimate effects, building design (including passive solar characteristics), use of additional heat sources, system functionality, and occupant comfort preferences. Heating energy use for the SMUD sites averaged 1.3 kWh/ft2-year and ranged from a low of 0.4 kWh/ft^2-year (site S9) to a high of 2.6 kWh/ft ^{2}-year (site S6).

Specific factors explaining energy use characteristics can be identified. For the Truckee sites, Site T9 was the highest "per ft^2" energy user. Contributing factors include lower insulation levels, poorer quality glazing, leaky ductwork, poor duct design (running second floor ducts up exterior wall cavities), system inefficiencies due to constrictions in supply and return ducts, functionality (system always uses auxiliary heat) and substantial shading from winter solar gains by an adjacent building. Site T8, which had the lowest monitored energy use of the Truckee sites, has a low occupancy rate and the homeowners use their wood burning stove frequently during the winter. Sites T4 and T5 also had low energy use; T4 because of the homeowners use of a wood burning fireplace insert for supplemental heat (~ one and a half cords burned during the winter), and T5 because of envelope renovations that happened in '96 and good passive exposure. T5 may have been using less energy due to poor system zoning and thermostat placement for the downstairs GHP, though we were made aware of this very late in the study and were not able to include this in the remediation work.

Sites T7 and T10 had slightly higher than average energy use. These were both dual-unit GHP sites, but were vastly different. T7 is a leaky cabin at the top of the Tahoe- Donner community with lots of glass. One heat pump was not working for the majority of the time the system was monitored, so the normalized energy use values may not be representative. T10 is a steel framed tent-like structure with two 5-ton water-to-water GHP units connected to storage tanks for a radiant floor system. Since the GHP systems was not commissioned until the middle of February, much of the energy consumed by the system was simply to reach equilibrium with the cold ground under the floor slab. In addition, construction workers were still frequently in and out of the structure during the monitoring, with doors often left open.

As for the sites with energy consumption close to the 3.3 kWh/ft ^{2}-year average, it was surprising to find both the highest and lowest energy consumers from the '96-98 study in this group (T1 and T2, respectively). Site T1, which had previously been the biggest energy consumer, is an older house with poor insulation and poor solar exposure. This house now has a wood burning stove that the homeowners use 6 to 8 hours a day. Site T2 is a fairly new house with a passive solar design and zoned radiant floor heating. Two possible contributing factors for higher T2 use are reduced solar gains during the 2001/2002 monitoring period and the owners' addition of a second load-side storage tank for their radiant floor system.

In the milder Sacramento climate, energy consumption was much lower, with an average of 1.3 kWh/ft^2-year. Site S9, which had the lowest energy use, is a townhouse unit in a multi-family complex with shared walls. It was new at the time of the 1998 study and has a favorable passive solar orientation. The low envelope exposure makes S9 an outlier relative to the other single-family detached Sacramento sites. There were four Sacramento sites with lower than average consumption. Site S1 has an efficiently designed envelope with well-oriented glazing and energy conscious owners. Despite these features, and the fact that they had a below average energy use for the heating season, they still used double the energy in the '96-'98 study.

The next lowest energy user was the lone commercial SMUD site, S2, which is a small office in a warehouse. This site was the highest "per ft^2" energy user (combined heating and cooling) in the '96-98 study due to high cooling loads. Site S7 is a compact 2-story retrofit site with no daytime occupancy. The GHP system has worked well for the homeowner, who has rigged a method of pressurizing the ground loop off of city water pressure to compensate for a very slow leak he has. Site S8 is a ranch house east of Sacramento that was well designed from an energy efficiency perspective. The homeowner cut his energy consumption in half compared to the previous study period probably due to energy conscious choices in thermostat settings.

Consistent with the prior monitoring study, the highest energy user was site S6. Curiously, the heating energy use was twice that of '96-98, possibly because the owners changed their occupancy habits, reduced their use of alternative fuel sources, or changed the set point preferences on their thermostat.

Two of the "new" Sacramento sites were found to have above average heating energy use. Site S12 is new home in Elk Grove on an un-landscaped lot (no trees to block solar gain). This 4,000 ft^2 residence has thermally inefficient steel framing (without rigid exterior insulation), and very high ceilings, all of which contribute to high heating energy use despite the pellet stove that is often used. Site S10 is a 1920's 2-story house near downtown Sacramento with brick exterior over un-insulated walls and an open basement connected to a ventilated crawlspace . The developed trees in the neighborhood block most solar gains to the house, making this site strongly heating-dominated. The two heat pumps in the basement share a return plenum that is undersized and leaky, as are the supply ducts. Th e primary factor driving high heating energy use are the uninsulated walls and leaky envelope.

4.1.2. Ground Loop Temperatures

An advantage often cited for GHP systems is the moderated ground exchange temperatures compared to air source equipment. GHP's have improved heat transfer characteristics due to refrigerant-to-water heat exchange resulting in an approximate 50% fluid-to-refrigerant temperature difference reduction relative to air-source equipment. For example, a 24°F temperature difference across refrigerant-to-air coil may be only 12 °F for GHP refrigerant-to-water coil. Any further benefit due to ground coupling (relative to outdoor air temperatures) would only improve the GHP's efficiency advantage. Table 5 compares average outdoor air temperatures with average loop return water temperature for all full-load operating data [12] at each site. 1998 data is also provided for comparison. Figure 3 plots typical ground loop return water temperature vs. outdoor air temperature for one site; plots for the remaining sites can be found in Appendix G.

For Truckee, the average return water temperature is 6°F warmer (31.2 vs. 25.2°F) than the corresponding outdoor air temperature during full-load heating system operation; although three high-use sites (T2, T9 and T10) demonstrate lower average return water temperatures. For Sacramento, the average return water temperature is 5.4°F warmer (47.8 vs. 42.4°F) than the corresponding outdoor air temperature during system heating operation, with two sites (S7 and S10) having lower average water temperatures than air temperatures. The 1998 and 2002 data are fairly comparable (see Appendix G) for both Sacramento and Truckee, leading to the conclusion that for the monitored sites, long-term temperature creep is not an issue.

[12] Full-load is defined as the GHP unit operating the full 15-minute monitoring interval.

Figure 3: Site T4 Heating Mode Return Water vs. Outdoor Air Temperature (Full Load Data)

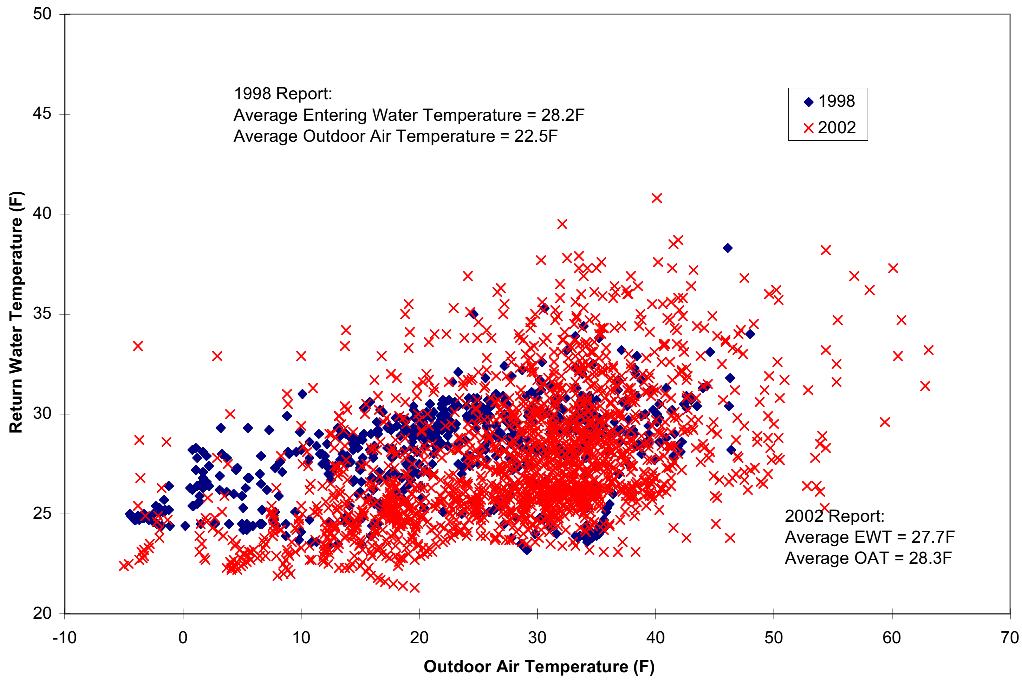


Table 5: Monitored Return Water vs. Outdoor Air Temperature

Site	1998 Monitoring Study Outdoor Air (°F)	1998 Monitoring Study Return Water (°F)	2002 Monitoring Study Outdoor Air (°F)	2002 Monitoring Study Return Water (°F)
T1	28.9	26.4	24.7	34.7
T2	36.2	29.8	31.3	28.1
T3	21.3	30.8	14.4	27.7
T4	22.5	28.2	28.3	27.7
T5	38.1	40.4	25.3	39.0
T6	-	-	26.7	27.6
T7	-	-	21.8	38.1
T8	-	-	14.8	29.0
T9	-	-	30.4	29.1
T10	-	-	34.2	30.8
Average	**29.4**	**31.1**	**25.2**	**31.2**
S1	51.6	52.5	-*	-*
S2	49.5	53.3	-*	-*
S6	40.9	45.4	39.7	48.0
S7	47.5	45.6	45.2	45.1
S8	47.7	60.7	44.7	59.4
S9	49.1	55.6	32.3	55.5
S10	-	-	46.3	36.9
S11	-	-	41.6	46.5
S12	-	-	42.8	43.6
S13	-	-	46.5	47.7
Average	**47.7**	**52.2**	**42.4**	**47.8**

"*" very limited full-load data for these sites

4.1.3. Peak Day Performance

Figures 4 and 5 plot key monitoring data for the coldest day during the monitoring period (similar plots for all other sites can be found in Appendix G). Figure 4 plots January 30 th data for site T3 when outdoor temperatures fell to approximately -5 °F (five degrees colder than the Truckee 0.6% design temperature). The GHP unit ran nearly continuously for the entire day. During the night the house temperature was gradually falling (to a low of 66 °F), indicating that the system could not quite keep up under extreme conditions. Around 9 AM, the indoor temperature began to increase as the outdoor temperature slowly rose above 0 °F. The ground loop return water temperature was very stable during the 24 hour period, ranging from 25-27 °F.

Figure 4: Site T3 - Peak Winter Day GHP Performance
January 30, 2002

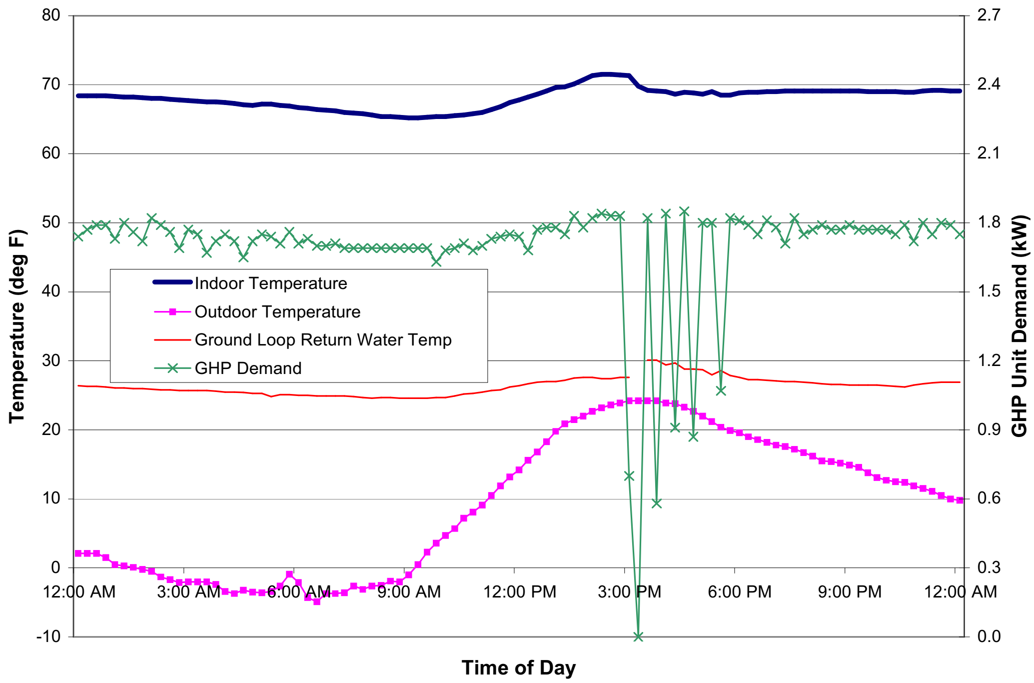
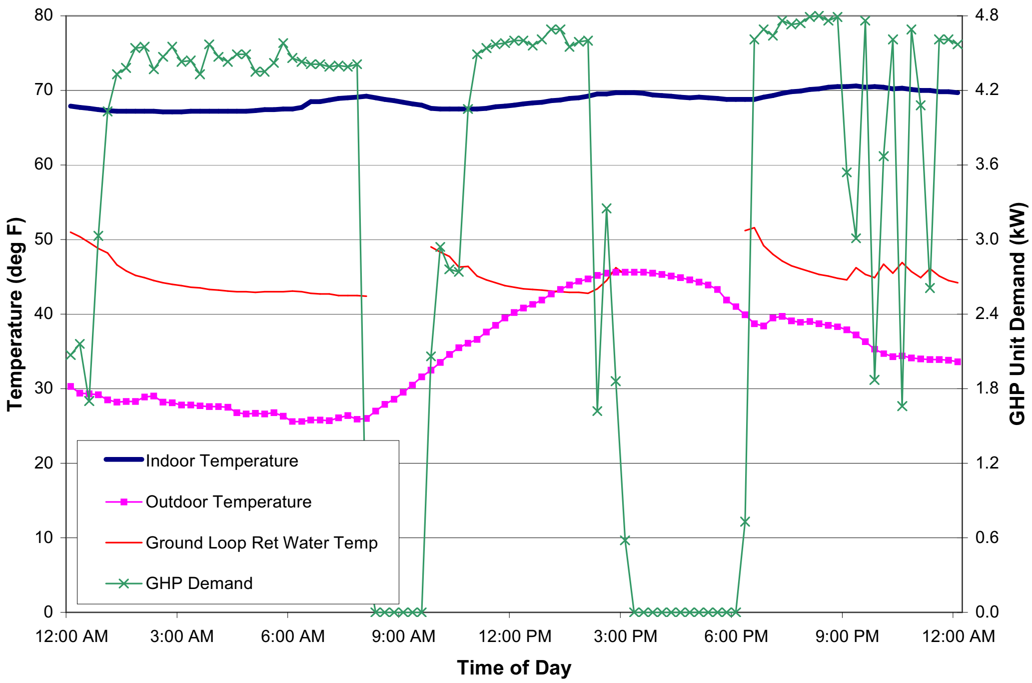


Figure 5 plots operating data for site S6. For Sacramento, low temperatures on January 30 th were more extreme than the ASHRAE 1% design temperature of 30 °F. The GHP unit ran all night to maintain indoor temperature at about 67 °F (the set point was likely 69 °F or higher). At around 8 AM, the unit was apparently turned off until about 10 AM, at which point it ran until satisfying the thermostat at 3 PM. Solar gains maintained indoor temperatures until around 6 PM at which time the unit was running to maintain temperatures slightly above 70 °F. The ground loop return water temperature fell from 50 °F at midnight to 43 °F during the long nighttime run cycle. Two hours on non-operation allowed the ground loop to recover 5-6 °F for the next operating cycle at 10 AM.

Figure 5: Site S6 - Peak Winter Day GHP Performance
January 30, 2002



4.2. Remediation Summary

The effort to identify and remediate problems at eight sites was a primary goal for this project. Tables 6 and 7 summarize problems (denoted by "H" if homeowner identified or "D" if determined in the course of the whole house diagnostic audit) and what remediation work was completed at each of the eight sites. A site-by-site description of work completed is provided in Appendix H and occupant survey results are presented in Appendix I.

Table 6: Identification of Problems and Remediation Effort for Truckee Sites

Site	Source	Problem	Remediation Effort
T1	H	High bills, supply air too cool and drafty.	1. Sealed crawlspace and insulated crawlspace door 2. Removed dampers on floor grilles
	D	Insulation defects, high duct leakage, excessive infiltration to crawlspace	3. Infiltration remediation 4. Sealed ducts 5. Sealed hole behind thermostat
T6	H	Unit wouldn't operate reliably, house very drafty, unit couldn't keep up with loads under extreme cold.	1. Repaired insulation defects where accessible, added ceiling insulation 2. Replaced floor grilles 3. Infiltration remediation
	D	Leaky ground loop, insulation defects, low air flow, infiltration to crawlspace	4. Sealed ducts 5. Leveled thermostat and sealed hole

(Table 6 continued)

			behind thermostat (infiltration)
T7	H D	High bills, lack of comfort, system not reliable One ground loop doesn't hold pressure, low airflow in one system, high air infiltration at roofline, infiltration to crawlspace	1. Removed dampers from 7 of 10 floor grilles (opened the other 3) 2. Infiltration remediation 3. Sealed ducts 4. Repaired insulation defects 5. Sealed crawlspace
T8	H D	GHP unit wouldn't operate due to leaking ground loop Ground loop does not hold pressure, low air flow, infiltration at roofline, infiltration into crawlspace.	1. Repaired insulation defects 2. Sealed crawlspace 3. Removed dampers on floor grilles 4. Infiltration remediation 5. Sealed ducts 6. Leveled and repaired thermostat
T9	H D	High energy bills, inability to reach a comfortable temp without using backup heat, reliability Low air flow, undersized return grille, poor roof insulation, riser ducts in exterior walls, leaky duct system	1. Removed dampers on floor grilles 2. Infiltration remediation 3. Sealed ducts and boots 4. Repaired insulation defects 5. Increased fan speed 6. Installed new return filter grilles 7. Sealed crawlspace

Table 7: Identification of Problems and Remediation Effort for SMUD Sites

Site	Source	Problem	Remediation Effort
S10	H D	High energy bills, reliability, system always uses backup heat Low air flow, extensive infiltration from basement (no door), leaky ducts	1. Installed insulated door to basement 2. Infiltration remediation
S11	H D	Reliability Infiltration, duct leakage, disconnect-ed duct, low airflow, high static pressure	1. Infiltration remediation 2. Sealed ducts 3. Repaired disconnected duct 4. Re-sized pipes from flow center(1)
S12	H D	High energy bills, system couldn't keep up with loads Poor insulation in kneewalls and soffits, low air flow, high static pressure, excessive duct leakage, system undersized, envelope very leaky for new construction	1. Added supply ducts 2. Upsized return duct 3. Added a return duct to small unit 4. Installed whole house fans 5. Infiltration remediation 6. Repair kneewall insulation defects 7. Draft stopped soffits 8. Added blown insulation to attic
S13	H D	Drafty, one room too hot in summer, too cold in winter Kinked duct to back bedroom	1. Rerouted duct

(1) the installing contractor had originally undersized the piping from the flow center to the three GHP units. They replaced the piping, hopefully solving the flow "starving" problem when all three units call.

4.2.1. Site T1 Remediation Summary

Site T1 is a 2,500 ft^2, 30+ year-old house located in a very shaded subdivision outside of Truckee. In 1998 monitoring, T1 used the greatest amount of heating energy (6.8 kWh/ft^2-year);

nearly double the average of the Truckee sites [13]. Since the 1998 study, the house has been sold and the new owner has installed a wood burning fireplace insert, which is used on a regular basis[14] and has reduced electrical usage to roughly half of the 1998 level. The diagnostic audit identified four key areas for remediation:

1. Low HVAC airflow (reduce duct leakage, remove floor grille dampers)
2. Seal crawlspace vents and any existing floor penetrations that contribute to infiltration
3. Use the blower door to identify and seal envelope leakage problem areas
4. Add insulation to the ceiling assembly (identified with infrared camera)

All remediation tasks, with the exception of #4 (can only be done during re-roofing), were completed by Chitwood Energy Management on February 13, 2002. Other problems, which could not be addressed, were a leaky floor system [15] and high duct system static pressure. Remediation work resulted in a reduction in total duct leakage from 317 cfm (at 25 Pascals) to 243 cfm (duct leakage to outside was reduced 38%, from 234 to 146 cfm). Measured supply airflow increased 14%, from 1026 cfm to 1167 cfm. Envelope leakage was reduced by 16%, from 3156 cfm (at 50 Pascals) to 2637 cfm.

Figure 6 plots daily "pre" and "post" remediation energy usage as a function of indoor-to-outdoor temperature difference. Two conclusions can be drawn from Figure 6. First, usage both "pre" and "post" remediation vary significantly for a specified indoor-to-outdoor temperature difference[16]. Second, the benefit due to remediation is difficult to quantify based on the small differences between the "pre" and "post" regression lines. Both of these impacts can be tied to the occupant's significant reliance on wood heating.

The "pre" and "post" regression relationships were used with the Ely, Nevada weather data to generate annual heating energy usage projections. The regression relationships resulted in annual savings of 6% (713 kWh per year) amounting to a total cost savings of $71 per year. With a $2,066 remediation expenditure at site T1, a simple payback of 29 years is projected.

4.2.2. Site T6 Remediation Summary

Site T6 is a 1,400 ft^2, 25-30 year old house located in Truckee. The occupant has experienced problematic heat pump operation for several years primarily due to a leaking ground loop causing the loop to lose pressure and ultimately the heat pump to stop running. In addition, the homeowner has expressed comfort concerns during extreme cold weather spells. T6 projected annual heating usage is 3.6 kWh/ft2-year, close to average for the Truckee sites. The diagnostic audit identified four key areas for remediation:

1. Low HVAC airflow (reduce duct leakage, replace floor grilles with low pressure drop grilles)
2. Seal crawlspace vents and any existing floor penetrations that contribute to infiltration

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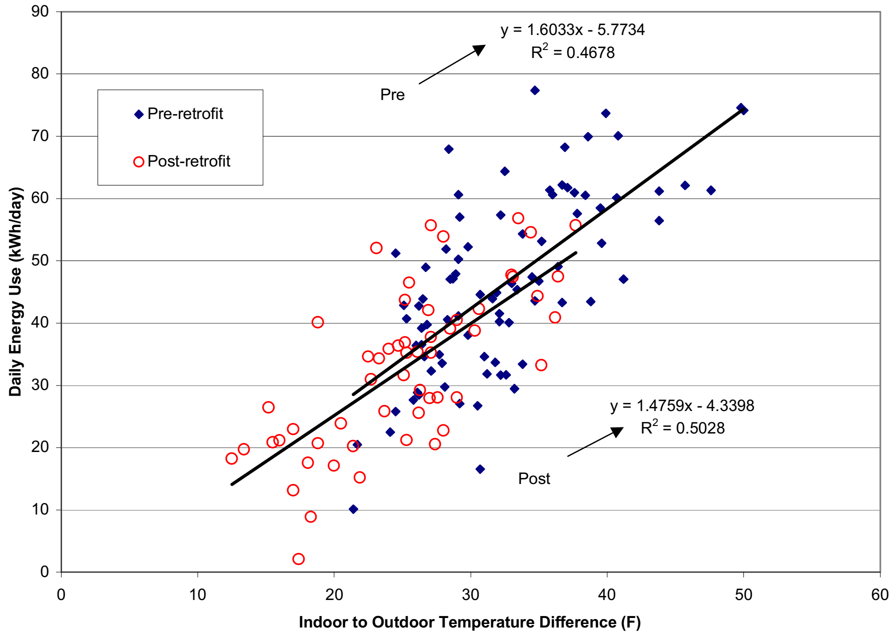
[13] Part of the high usage can certainly be attributed to the absence of any beneficial solar gains.
[14] By their own estimates, wood burning provides about 25% of their annual heating. Regular use of the fireplace insert complicates the quantification of remediation benefit.
[15] The floor space between first and second floors was very well connected to the attic. This common infiltration path must be properly addressed when the house is being built, since no access exists later.
[16] The high degree of variation for a specific temperature difference is evidence of significant variation in supplemental heat usage. For example, at 35°F difference daily usage varies from ~30 to 65 kWh/day.

3. Use the blower door to identify and seal envelope leakage problem areas
4. Add ceiling insulation to the attic

Figure 6: Site T1 Monitored Energy Use
Pre- and Post-Retrofit



Remediation work was completed by Chitwood Energy Management on February 14, 2002. Total duct leakage was reduced from 347 cfm (at 25 Pascals) to 228 cfm (duct leakage to outside was reduced 46%, from 211 to 113 cfm). Measured supply airflow increased 20%, from 990 cfm to 1184 cfm. Envelope leakage was reduced by 20%, from 2313 cfm (at 50 Pascals) to 1839 cfm. Figure 7 plots daily "pre" and "post" remediation energy usage as a function of indoor-to-outdoor temperature difference. The T6 data shows a much clearer remediation benefit than site T1, since the owner did not use supplemental heating during the monitoring period.

The "pre" and "post" regression relationships were used with the Ely, Nevada weather data to generate annual heating energy usage projections. The regression relationships resulted in a 20% annual savings estimate (1400 kWh per year) amounting to a total cost savings of $140 per year. With a $2,604 remediation expenditure at site T6, a simple payback of 19 years is projected.

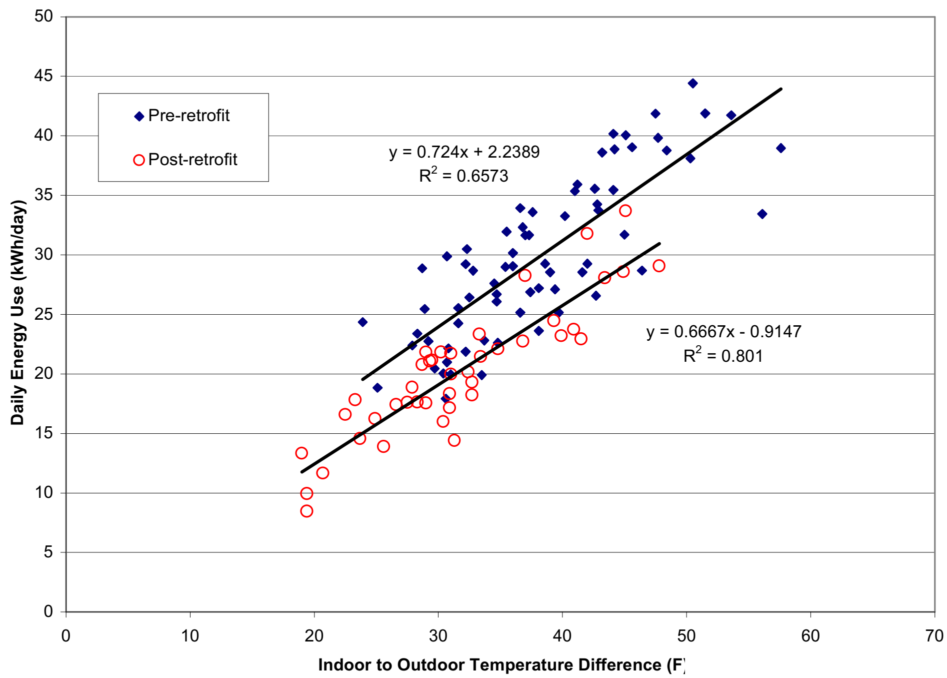
4.2.3. Site T7 Remediation Summary

Site T7 is a 1,625 ft^2, 20+ year old house located in Truckee. The house has been remodeled resulting in construction anomalies between the original house and the addition [17]. The house has two GHP units (a 3.5 ton a 2 ton), the smaller of which wasn't operational at the start of the project due to a leaking ground loop. A depressurized flow center was installed as part of this project to remedy that problem. The occupants have also had general complaints relating to

[17] Additions can often compromise the performance of a house, if not properly integrated to insure that the thermal/pressure barrier separating conditioned and unconditioned space remains intact.

comfort, high energy bills, and the GHP systems inability to keep up with loads under extremely cold weather conditions. T7 projected annual heating usage is on the high side for the Truckee sites at 4.3 kWh/ft^2-year. The diagnostic audit identified four key areas for remediation:

Figure 7: Site T6 Monitored Energy Use Pre- and Post-Remediation Effort



1. Low HVAC airflow (reduce duct leakage, remove dampers from floor grilles)
2. Seal crawlspace vents and any existing floor penetrations that contribute to infiltration
3. Use the blower door to identify and seal envelope leakage problem areas
4. Repair accessible insulation defects identified by the infrared camera.

Chitwood Energy Management completed the remediation work on February 12, 2002. One problem area, which could not be accessed as well as hoped were the tongue and groove ceiling[18].

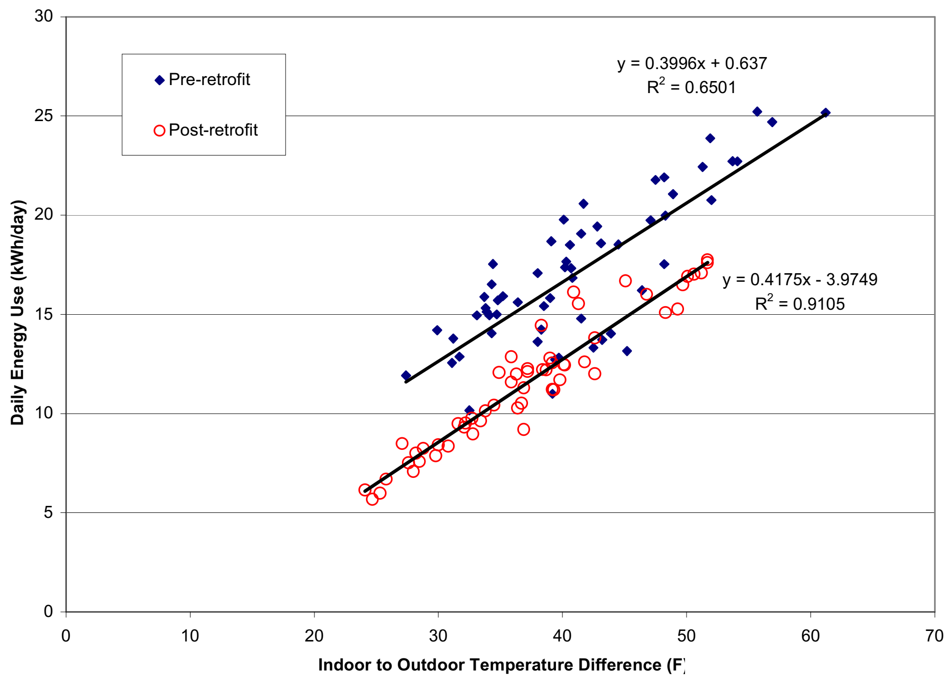
Remediation work resulted in a reduction in total Unit #1 duct leakage from 172 cfm (at 25 Pascals) to 138 cfm (duct leakage to outside was reduced 41%, from 108 to 64 cfm). Unit #2 duct leakage was reduced from 182 cfm (at 25 Pascals) to 118 cfm (duct leakage to outside was reduced 50%, from 125 to 63 cfm). Measured Unit #1 supply airflow increased 20%, from 1162 cfm to 1398 cfm, and Unit #2 was reduced from 945 cfm to 853 cfm. Envelope leakage was reduced by 28%, from 3851 cfm (at 50 Pascals) to 2791 cfm.

Figure 8 plots daily "pre" and "post" remediation energy usage as a function of indoor-to-outdoor temperature difference. The remediation benefit is very evident in Figure 8.

[18] T&G ceilings are often very leaky. It is difficult to seal from the inside without leaving a visible caulk bead on the wood members.

The "pre" and "post" regression relationships were used with the Ely, Nevada weather data to generate annual heating energy usage projections. The regression relationships resulted in a 31% annual savings estimate (1151 kWh per year) amounting to a total cost savings of $115 per year. With a $2,563 remediation expenditure at site T7, a simple payback of 22 years is projected.

Figure 8: Site T7 Monitored Energy Use
Pre- and Post-Retrofit



4.2.4. Site T8 Remediation Summary

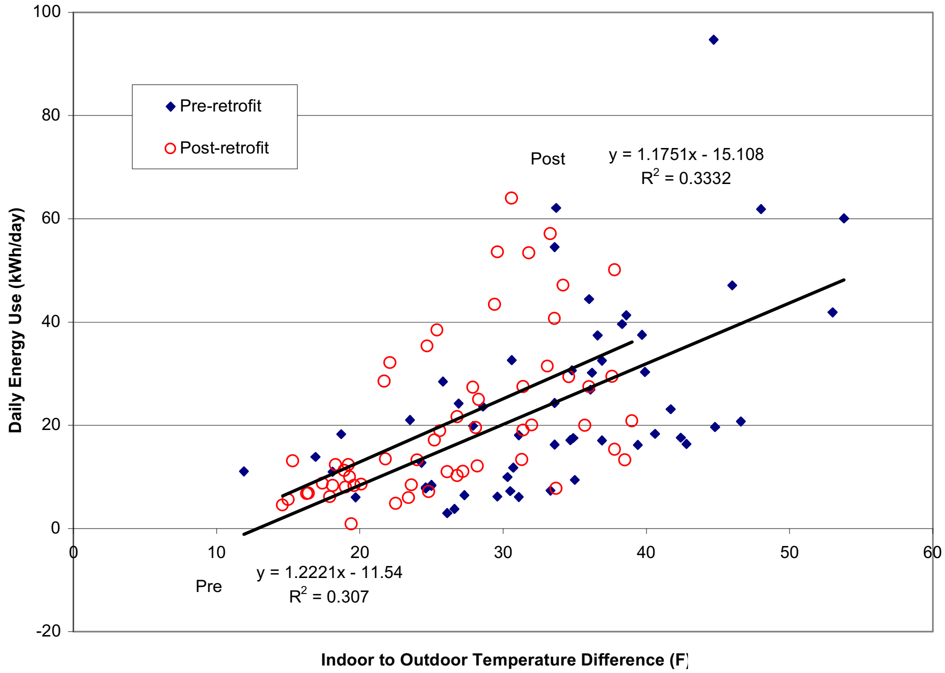
Site T8 is a 1,650 ft^2, 10+ year old house located in Truckee. The house has one GHP unit, due one of which wasn't operational at the start of the project due to a leaking ground loop. A depressurized flow center was installed to remedy this problem. T8 projected annual heating usage is very low for the Truckee sites at 1.0 kWh/ft2-year due to significant supplemental heating. The diagnostic audit identified three key areas for remediation:

1. Low HVAC airflow (reduce duct leakage, remove dampers on floor grilles)
2. Seal crawlspace vents and any existing floor penetrations that contribute to infiltration
3. Use the blower door to identify and seal envelope leakage problem areas

Chitwood Energy Management completed the remediation work on February 11, 2002. Remediation work resulted in a reduction in total duct leakage from 205 cfm (at 25 Pascals) to 95 cfm (duct leakage to outside was reduced 78%, from 95 to 21 cfm). Measured supply airflow increased 24%, from 974 cfm to 1204 cfm. Envelope leakage was reduced by 23%, from 2380 cfm (at 50 Pascals) to 1838 cfm.

Figure 9 plots daily "pre" and "post" remediation energy usage as a function of indoor-to-outdoor temperature difference. The T8 "post" data actually shows higher usage than prior to remediation. Part of this is due to an average 2 °F warmer indoor temperature after the remediation work had been completed. No additional analyses was completed for T8, since the regression relationships do not indicate any savings.

Figure 9: Site T8 Monitored Energy Use
Pre- and Post-Retrofit



4.2.5. Site T9 Remediation Summary

Site T9 is a 2,050 ft^2, 20+ year-old house located in Truckee. The house was the highest heating energy user "per ft^2" of the 10 Truckee sites at 5.2kWh/ft^2-year. Homeowner complaints included high energy bills, excessive auxiliary heat use under cold conditions, and overall system reliability. The diagnostic audit identified four key areas for remediation:

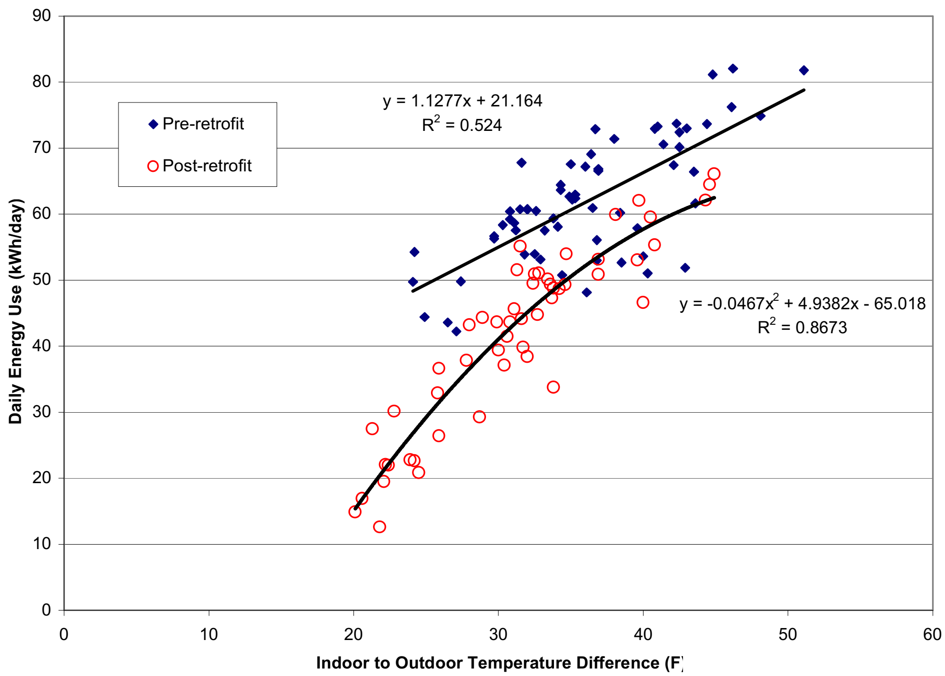
1. Replace the duct system (the system was running on low fan speed due to noise concerns at high speed and apparently undersized ducts).
2. Reduce duct leakage and remove dampers on the floor grilles
3. Seal crawlspace vents and any existing floor penetrations that contribute to infiltration
4. Use the blower door to identify and seal envelope leakage problem areas
5. Repair accessible insulation defects

Chitwood Energy Management completed the remediation work on February 15, 2002.

Remediation work resulted in a reduction in duct leakage to outside from 430 cfm (at 25 Pascals) to 315 cfm (a 27% improvement). Measured supply airflow more than doubled from 905 cfm to 2150 cfm[19]. Envelope leakage was reduced by 29%, from 3350 cfm (at 50 Pascals) to 2370 cfm.

Figure 10 plots daily "pre" and "post" remediation energy usage as a function of indoor-to-outdoor temperature difference. The remediation benefit is magnified by the fact that site T9 was the highest Truckee energy user.

Figure 10: Site T9 Monitored Energy Use
Pre- and Post-Retrofit



The "pre" and "post" regression relationships were used with the Ely, Nevada weather data to generate annual heating energy usage projections. The regression relationships resulted in a 22% annual savings estimate (3416 kWh per year) amounting to a total cost savings of $340 per year. With a $2,336 remediation expenditure at site T9, a simple payback of 7 years is projected.

4.2.6. Site S12 Remediation Summary

Site S12 was the only Sacramento site where a majority of the remediation work was completed by the end of March[20]. Limited data is available to compare to pre-monitoring data, but unfortunately the data are at small "indoor-to-outdoor temperature differences" which doesn't

[19] The major restriction on the duct system was woefully undersized return grilles. The return grille configuration was modified to allow the system to operate at high speed without excessive noise.

[20] Unlike the Truckee sites, where Chitwood Energy Management represented "one stop shopping" for successful remediation work, we had more difficulty completing the work in Sacramento. Experienced contractors with "whole house" remediation abilities are few and far between. Performance Energy provided the most comprehensive service for the Sacramento sites.

provide great confidence in extrapolating to higher temperature differences for use in full-year savings projections.

Site S12 is a 4,050 ft^2, one year old house located south of Sacramento. The house has two GHP units, a 4 ton and a 3 ton. The 4 ton unit is clearly undersized and is supplemented by a pellet stove in the winter. Our hope in pursuing remediation for site S12 was that the efforts would provide sufficient load reduction benefit to allow the 4 ton unit to meet the reduced space conditioning loads. The homeowners have also expressed concern over high energy bills in their new house. S12 projected annual heating usage was determined to be the second highest at 2.1 kWh/ft2-year. The diagnostic audit identified four key areas for remediation:

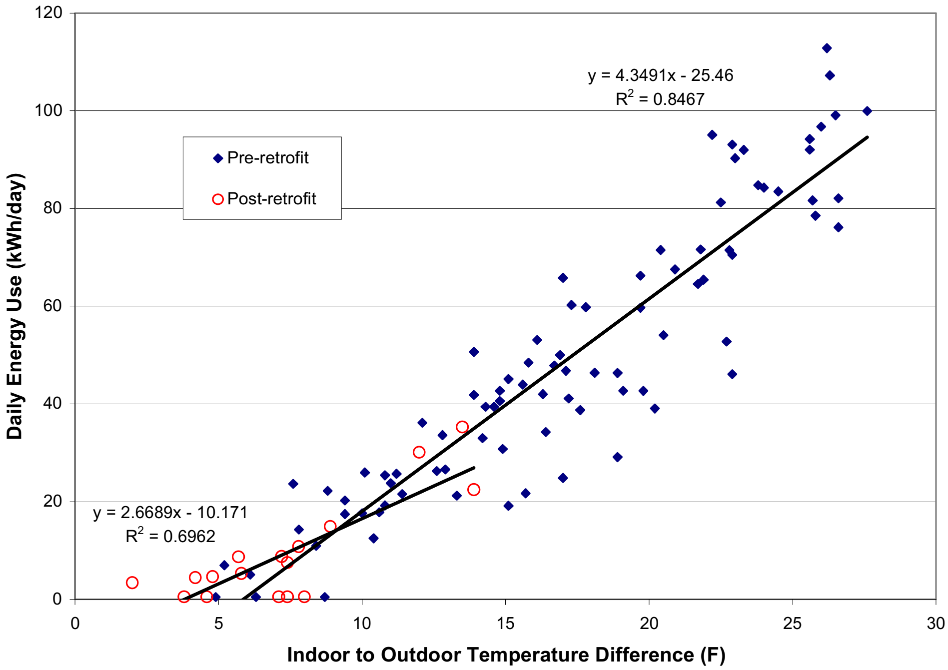
1. Low HVAC airflow (reduce duct leakage, upsize return duct on the 4 ton unit and add supplies to both systems to reduce duct restriction).
2. Several interior wall cavities (identified with the infrared camera) represent a major defect in the thermal envelope. These cavities need to be isolated (install draft stopping) and insulated.
3. Use the blower door to identify and seal envelope leakage problem areas (53 leaky recessed lights are a prime leakage point).
4. Add attic insulation and repair poor kneewall and other ceiling insulation defects.

Performance Energy of Sacramento completed a majority of the remediation work in late March and early April. One remediation recommendation from Performance Energy was to install whole house fans. Three were installed with two paid for by this project. These fans, if used properly by the homeowners, will allow for summer pre-cooling of the house, reducing subsequent day cooling loads and loading on the ground loop.

In early May, Five Star Performance Insulation completed their work which included significant attic kneewall repairs, draftstopping interior columns connected to the attic, and addition of blown ceiling insulation to all accessible attic areas. One critical area not addressed was the thermal short circuit through the steel framed exterior walls. Although Title-24 requires rigid insulation on the exterior of steel framing, this was apparently not required by the building inspectors during construction. To retrofit the house with insulation would be very costly.

Figure 11 plots daily "pre" and "post" remediation energy usage as a function of indoor-to-outdoor temperature difference. The mild weather since the end of March has resulted in only three data points at greater than 10 °F temperature difference. With this limited data we are unable to make reliable full-year heating projections.

Figure 11: Site S12 Monitored Energy Use
Pre- and Post-Retrofit



4.2.7. Sites S10 and S11 Remediation Summary

The two remaining SMUD sites did not complete remediation efforts early enough to gather good post-remediation data. A brief description of the problems and the remediation work follows.

Site S10, located close to downtown Sacramento, is a ±75 year old house located in an area with mature trees. The 3,650 ft^2 house is wood framed construction with an exterior brick veneer and uninsulated walls. The house also has single glazed windows resulting in an inefficient building envelope with space conditioning loads strongly heating-dominated. Two GHP units, located in the basement, serve the house with one unit serving the downstairs floor and one the upstairs. The systems share a single return duct system[21]. Another key thermal defect is the lack of a door on the stairs leading to the basement. The remediation work completed at S10 included installation of a custom door isolating the basement from the house and general infiltration remediation on the building envelope. The net impact of these measures was to reduce blower door infiltration by 44%, with a large fraction of the benefit likely attributed to the custom door. Duct leakage was reduced 38%, but leakage is still fairly high since much of the return duct system was not accessible (due to using interior wall cavities). One suggestion from an HVAC contractor was to move the second floor unit to the attic and reconfigure the ground loop and ducting. Although this would improve system performance, the cost would be very high and the modification would not address the primary problem which is the fundamental inadequacy of the building envelope.

Site S11 is located in a semi-rural area south of Sacramento. This 5 ,000 ft^2 house has three GHP units. The primary problem with the units prior to the project was unreliable operation (systems

[21] The duct system uses building cavities as part of the return system. These cavities are notoriously leaky.

would shut down under high load situations). The installing HVAC contractor was continuing to work on the units and finally identified what may be the primary cause of the problem. The piping from the ground loop flow center to the three units (all located in a mechanical room) was significantly undersized. This would “starve” one or more of the units, when all three were calling for heating or cooling. Low flow would cause the unit to “trip off” on low or high pressure, depending upon which operating mode it was in. Other issues addressed by remediation in this project included duct leakage reduction on all three units and envelope infiltration remediaton. Duct leakage was reduced by 25%, 29%, and 72%, respectively, on the three units with the largest benefit due to the repair of Unit #3’s disconnected return duct in the crawlspace. Envelope leakage was reduced by 50%, with roughly a third of the benefit due to the duct leakage reduction.

4.3. DOE-2 Performance Projections

The DOE-2 projections presented in this section update the 1998 study based on current utility rates. Utility rates have been volatile over the past year and it is not clear what the future relationship between retail electric and gas rates will be.

Tables 8 and 9 summarize DOE-2 results for Truckee and Sacramento, respectively. Miscellaneous (“Misc”) energy use includes blower fan energy, crankcase heater energy, and GHP ground loop pump energy use. Listed peak demand for TDPUD is the average of the 4-6 PM GHP demand on an assumed 4°F winter design day. SMUD peak demand is the 2-8 PM average for the peak Sacramento summer day. The total annual utility cost includes household lighting and miscellaneous electric use of 5608 kWh/year in all cases.

In Truckee, projected GHP new construction savings are roughly $750/year vs. a standard efficiency furnace and $450/year vs. a condensing furnace. The expected impact due to performance variations (best and worst scenarios) results in a ±$140 change in the expected savings. As building loads increase, the expected annual savings also increase. Retrofit savings are slightly higher due to greater projected annual heating loads. A favorable electric rate relative to existing natural gas costs is the primary factor influencing GHP economics in Truckee.

Table 8: DOE-2 Performance Projections for Truckee

System Type	Load Case	Loop Type	GHP Case	Heating therms	Annual kWh Usage Clg	Htg	Misc	Peak kW	Annual Cost($)
New Construction									
Gas - 78%	Med	n/a	n/a	1012	0	0	1021	0.3	$2169
Gas - 78%	High	“	“	1121	0	0	1141	0.3	$2332
Gas - 92%	Med	“	“	795	0	0	1021	0.3	$1867
GHP	Med	Vert	Typ	0	0	5726	1859	2.5	$1418
	“	“	Best	0	0	4775	1397	2.0	$1277
	“	“	Worst	0	0	6481	2382	3.3	$1546
	High	“	Typ	0	0	6390	2056	2.8	$1504
Retrofit									
Gas - 78%	Med	n/a	n/a	1144	0	0	1152	0.3	$2365
Gas - 78%	High	“	“	1261	0	0	1271	0.3	$2540
GHP	Med	Vert	Typ	0	0	6683	1885	2.6	$1517
	High	“	Typ	0	0	7454	2085	2.8	$1614

Table 9: DOE-2 Performance Projections for Sacramento (update for $.105)

System Type	Load Case	Loop Type	GHP Case	Heating therms	Annual kWh Usage Clg	Htg	Misc	Peak kW	Annual Cost($)
New Construction									
Gas/AC-10 SEER	Med	n/a	n/a	361	2470	0	686	4.1	$1233
Gas/AC-10 SEER	High	"	"	584	3636	0	1032	4.1	$1547
Gas/AC-12 SEER	Med	"	"	361	2065	0	686	3.5	$1190
ASHP-10 SEER	Med	"	"	0	2470	3824	729	4.1	$1386
GHP	Med	Vert	Typ	0	1747	1799	710	3.3	$1096
	"	"	Best	0	1247	1395	463	2.3	$975
	"	"	Worst	0	2774	2039	1051	4.8	$1264
	High	"	Typ	0	2792	3155	1195	3.5	$1399
	Med	Horz	Typ	0	1689	1838	718	3.1	$1094
	High	"	Typ	0	2587	3177	1198	3.3	$1380
Retrofit									
Gas/AC-10 SEER	Med	n/a	n/a	449	3094	0	878	5.2	$1381
Gas/AC-10 SEER	High	"	"	711	4491	0	1313	5.3	$1756
ASHP-10 SEER	Med	"	"	0	3094	4555	908	5.2	$1547
GHP	Med	Vert	Typ	0	2141	2260	993	4.0	$1215
	High	"	Typ	0	3264	3879	1656	4.5	$1573
	Med	Horz	Typ	0	2092	2317	1010	3.7	$1218
	High	"	"	0	3066	3919	1679	4.1	$1558

In Sacramento, projected GHP new construction savings are roughly $150/year vs. a standard Gas/AC system and $290/year vs. an ASHP. The expected impact due to performance variations results in a $30 increase in annual costs for the "worst" case and savings of $260/year in the "best" case (vs. Gas/AC). As building loads increase, the expected annual savings increase slightly. Retrofit savings are approximately 20% higher than the projected new construction savings due to the higher loads. The SMUD savings will vary with house size and usage due to the three level tiered residential rate structure. Bigger houses with higher usage will typically have slightly smaller savings and smaller, lower usage houses will have higher savings [22].

4.4. Desuperheater and DGWH Evaluation Results

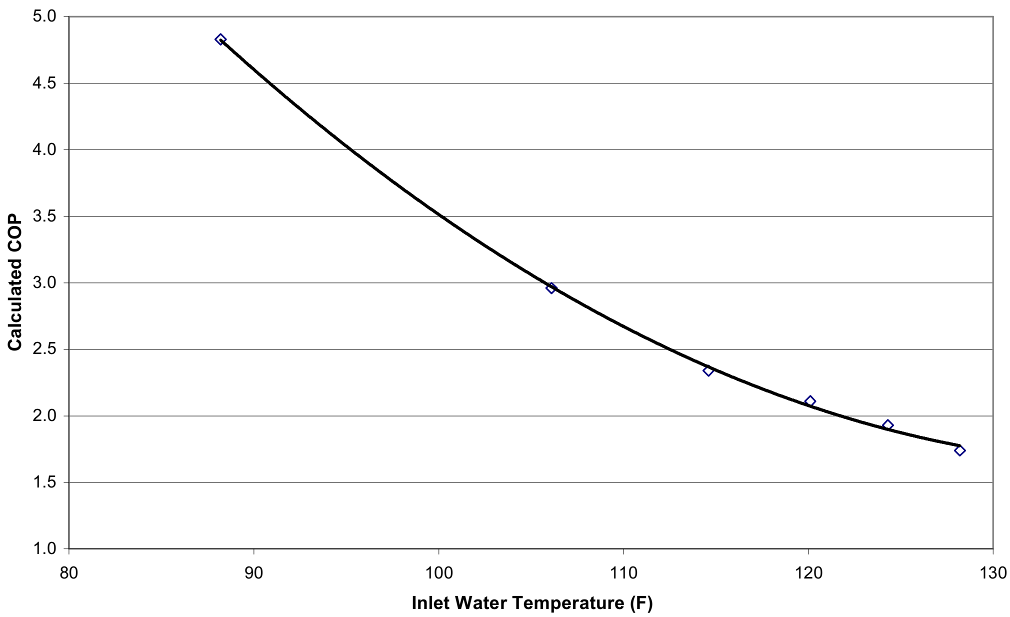
Annual savings, including desuperheater pumping energy costs, range from $33 to $148 in Sacramento, and $67 to $118 in Truckee. With the estimated $780 incremental cost for installation of the desuperheater, simple paybacks are projected to be 5 and 24 years for Sacramento electric and gas DHW installations, respectively, and 9 and 12 years for Truckee installations. DGWH performance was based on monitoring performed under PG&E's 1999 Geothermal Heat Pump Demonstration Program. Figure 12 below plots monitored efficiency, in terms of COP, as a function of the water temperature entering the DGWH. Performance is best when inlet water temperatures are low. At normal "hot" inlet water temperatures around 125 °F, COP's fall to about 1.7, much lower than the 4.0 COP at 95 °F inlet water temperature.

[22] In comparison to the furnace/air conditioner base case; GHP savings will increase vs. ASHP base case.

Table 10: Desuperheater Results Summary

Utility	Base DHW Cost		Desuperheater $ savings		Simple Payback (years)	
	Gas	Electric	Gas	Electric	vs. Gas	vs. Elec
SMUD	$152	$557	$33	$148	24	5
TDPUD	$342	$458	$67	$86	12	9

Figure 12: Monitored DGWH COP vs. Inlet Water Temperature



An annual performance model was developed based on the PG&E results. Simulations were completed using SMUD and TDPUD utility rates. Table 11 summarizes the results. In SMUD territory, the DGHW is more expensive to operate than a standard natural gas water heater, however versus electric water heating the DGWH will pay for itself in eight years. In Truckee, projected paybacks are 9 years vs. electric and 17 years vs. natural gas.

Table 11: DGWH Results Summary

Utility	Base DHW Cost		DGWH $ savings		Simple Payback (years)	
	Gas	Electric	vs. Gas	vs. Elec	vs. Gas	vs. Elec
SMUD	$152	$443	(-$36)	$255	n/a	8
TDPUD	$342	$458	$118	$234	17	9

4.5. Vertical Helix Assessment

The vertical helix ground loop offers the potential of significantly lower cost that traditional vertical bore systems which typically cost roughy $6-$7 per foot, including manifolding costs. Five of the nineteen monitoring sites had vertical helix ground loops. The vertical helix involves using a 30-36" auger bit to bore 20 to 60 deep. A 24-30" pre-fabricated spiral of ½' or ¾" polyethylene pipe is then lowered (with the spiral supported to maintain spacing) into the hole and the hole is carefully backfilled. The main advantage of the vertical helix is much quicker installation time than conventional vertical bores. The primary disadvantages are the need to:

- have non-rocky soils (to allow for augering)
- have soils which are not overly sandy (the hole will collapse).
- maintain uniform vertical spacing of the spiral after it is placed and backfilled

March Equipment Company in Sacramento is the primary supplier of vertical helix ground loops in Northern California, although at the current time they are not aggressively promoting the system. According to March, typical residential sizings indicate a 30-inch, thirty foot deep helix is equivalent to one ton of vertical ground loop (180-200 foot deep bore). Installed costs are for the helix are ~$900 per ton, or roughly $300-$400 less than a vertical bore. Since the GHP market is still not fully developed in Northern California these costs should come down with increased volume.

Two sites, S11 are S12, were felt to have inadequately sized vertical helix ground loops prior to the start of this project. Both of these were evaluated with the Right Suite ™ load and loop sizing software. Site S11, as discussed in section 4.2.7 ., suffered from undersized piping problems which caused a flow restriction under high demand situations. Loop sizing results, included in Appendix J, demonstrate the need for nine 196 foot vertical bores. Based on the March helix equivalence, this is roughly equal to nine thirty foot helix. The seven sixty foot helix loops installed are more than adequate, provided the local soil conditions are consistent with the loop sizing assumptions.

Site S12 loop sizing indicates eight 212 foot vertical bores (equal to 8 or 9 thirty foot helix loops). Eight 30 foot helix loops were installed at S12 which appears to be marginal. Winter loop temperature minimums at Site S12 were slightly below 40 °F, but not as low as some of the other Sacramento area sites. If additional capacity becomes necessary at site S12, more helix loops will not to be installed, however if the remediation efforts provide sufficient load reduction, the existing ground loop should be adequate.

4.6. GHP's, Construction Quality, and Remediation

Geothermal heat pumps represent an efficient space conditioning technology which gains a significant operating efficiency advantage from the refrigerant-to-water connection with the ground loop. With fairly high GHP incremental costs in California ($1,800-$2,000 per ton), high space conditioning loads and favorable gas/electric utility rates are needed to provide reasonable homeowner paybacks. In Truckee, significant operating cost savings are projected based on the presence of both of these factors. In the Sacramento area, and much of the populated areas of California, these factors are not present resulting in less economic justification for GHP [23]. In either case, it is significant to recognize that a successful GHP installation is characterized by climate-appropriate building design, quality control during construction, a tight building

[23] Other non-economic benefits of GHP's include noise reduction, elimination of outdoor condensing unit, reduced peak demand, and reduced environmental impacts due to lower annual energy consumption.

envelope and duct system, proper GHP system and duct sizing, and system commissioning. For retrofit applications, it becomes more complicated since the GHP system must be integrated into an existing home (with unknown envelope and duct defects). Care should be taken to insure that the building envelope is of adequate thermal "quality" and that the GHP system will integrate well with the existing house and the occupants' comfort requirements. A "house as a system" integrated approach is essential to maximize the extent to which the house is improved prior to designing and installing an expensive GHP system.

To quantify the potential of "whole house" improvements relative to incremental GHP capacity, a few energy efficiency measures were evaluated for cost-effectiveness. In Truckee, tight ducts and a tight building envelope were evaluated and in Sacramento, tight ducts and low- E^2 glazing. The ASHRAE sizing algorithm in MICROPAS6 was used to project the potential sizing reduction on a 1,700 ft^2 house complying with the current Residential Building Standards. For new construction, tight ducts (with third-party verification of duct leakage) were assumed to cost $400 more and reduce duct leakage from 22% to 6% of total HVAC airflow. A blower door tested tight envelope was estimated to cost $500 more [24]. Low-$E^2$ glazing incremental cost was estimated at $1.50 per ft^2 of glazing.

Table 12 summarizes the costs and benefits of implementation of these key features in new construction applications. The benefits were computed based on the potential capacity reduction at an incremental cost of $1,800 per ton. For new construction, the incorporation of these selected measures was found to be highly cost-effective, especially in Truckee where the capacity benefit is greater. For retrofit applications, similar to the work completed in this project, the cost for implementing these measures would be at least twice the cost shown in Table 12[25]. Getting things right the first time is the key message. Proper house design and construction quality control are vital to insuring adequate whole house performance and comfort.

Table 12: Measure Cost-Effectiveness

	Estimated Cost	Capacity Benefit
Truckee		
Tight ducts	$400	$1285
Tight Envelope	$500	$1004
Sacramento		
Tight ducts	$400	$614
Low-E^2 glazing	$480	$734

5. Conclusions

This project expanded on the 1998 study documenting GHP system performance in SMUD and TDPUD service territories. A key component of the 2002 project was to perform and assess the value of remediation efforts at eight underperforming sites. Specific tasks included:

[24] To achieve a tighter envelope, more effort is needed in draftstopping interior wall cavities and floor assemblies, sealing penetrations, and caulking at floor/wall/ceiling interfaces.
[25] In almost all circumstances, the impact of the remediation work would not be as great as if the work were originally performed correctly. Reduced access results in reduced benefits.

- Identify sites with operational problems
- Monitor the sites in detail to determine base case performance
- Perform diagnostic audit to assess remediation potential
- Implement recommended remediation measures
- Perform post-remediation monitoring
- Quantify the benefit

The remediation component was the most interesting aspect of the project as it allowed for "closing the loop" between savings projections and actual benefit to the homeowner. The reality of this exercise was that the remediation work at the Sacramento sites came too late in the project to allow for any definitive savings projections. Truckee sites had significant post-monitoring data, but supplemental heat use at some of the sites clouded any quantification of the benefit.

Key conclusions from the remediation work:

1. Qualified contractors with experience in "whole house" performance issues are not common. Chitwood Energy Management is a unique contractor who can provide a wide range of services related to HVAC issues, insulation installation, and envelope leakage mitigation. Chitwood was able to perform remediation work at the five Truckee sites in one week. In contrast, in Sacramento we dealt with numerous contractors [26] in trying to implement the remediation work.

2. Remediation of existing sites is generally a difficult and costly proposition. It is extremely important to improve the quality of new homes as it relates to HVAC airflow, duct leakage, and envelope leakage. This is especially true for costly GHP systems for two reasons: First, gas furnaces are much higher capacity than heat pumps allowing them to better mask sizing shortcomings, and second, properly installed energy features will often be more cost-effective than adding incremental GHP capacity.

3. At the five Truckee sites, monitoring data demonstrated a clear benefit from the remediation work at three of the sites. At two of the three, simple paybacks of around 20 years were projected. At the third (the highest per ft^2 energy user), favorable paybacks of around seven years are projected. All five Truckee sites had favorable comments regarding the remediation work.

Other conclusions from this project include:

4. Projected full-year GHP heating energy use ranged from 0.4 to 5.2 kWh/ft^2-year with average TDPUD usage approximately two and half times that of the SMUD sites. TDPUD usage varied from 1.0 to 5.2 kWh/ft^2-year (average of 3.3) and SMUD varied from 0.4 to 2.6 kWh/ft^2-year (average 1.3)

5. Monitored return water temperatures during full-load operation indicate a GHP advantage of 5 to 6°F vs. corresponding outdoor air temperatures. The warmer temperatures contribute to higher GHP operating efficiencies.

[26] All but one of which were lacking an understanding of the "house as a system" concept.

6. No evidence of heating season ground creep effects were observed in comparing the 1998 data with the current 2002 data. In Truckee, return water temperatures typically approach 30°F in December and vary only a few degrees through the course of the heating season. In SMUD territory where heating system operation is less consistent day-to-day, return water temperatures reach a minimum during periods of heavy loading, but then recover quickly.

7. DOE-2 performance projections indicate annual savings of approximately $750 for the "typical" TDPUD case. A combination of efficient GHP performance and favorable gas/electric utility rates contributed to the savings level. Typical SMUD savings of about $150 (vs. gas furnace /air conditioner base case) are largely due to summer cooling savings ; relatively low natural gas rates result in small heating season savings. Relative to an ASHP base case, "typical" SMUD GHP customers can expect annual savings of ~$290 per year.

8. DOE-2 projected "typical" SMUD demand savings (averaged over the 2-8 PM peak period) were ~20% (0.8-1.0 kW) vs. standard 10 SEER cooling equipment. With TDPUD's winter peak period, maximum projected demand was expected to increase from 0.3 to about 2.5 kW relative to the standard 78% AFUE gas furnace.

9. A desuperheater model developed based on field-monitored performance indicates favorable customer economics (5 year projected simple payback in SMUD territory, 9 years in TDPUD) when compared to electric water heating, but not relative to gas water heating (paybacks ranging from 12 to 24 years). One downside to desuperheaters in Truckee is that they scavenge heat normally used for space heating. Given that complaints of low supply air temperature are not uncommon, a desuperheater may accentuate that problem.

10. Dedicated geothermal water heaters were found to generate favorable economics relative to electric water heating (SMUD projected payback of 8 years, Truckee payback of 9 years), but again not versus gas water heating (higher DGWH costs than for gas water heating in SMUD territory, 17 year projected payback in TDPUD territory). DGWH's are best suited for SMUD non-natural gas areas where the economics are good and where DGWH heat extraction during the summer will improve ground loop performance.

11. Assuming a customer "10 year simple payback criteria", GHP's are currently viable in TDPUD service territory (ten year savings of $7,500 allows for $2,500 incremental cost per ton for a 3 ton unit). In SMUD territory, GHP's are viable at $970 per ton incremental cost vs. air-source heat pumps (ten year savings of $2,900 divided by 3 ton system), but are not cost-effective vs. the more common furnace/air conditioner installation. These conclusions are sensitive to the balance between gas and electric rates.

12. Several key energy efficiency measures were analyzed to determine if they provided a cost-effective means of reducing the GHP equipment sizing in new construction. For Truckee, the load (and corresponding capacity) reduction for both tight ducts and a tight envelope [27] were more cost-effective than additional GHP capacity. Likewise for Sacramento, tight ducts and Low-E^2 high-performance windows demonstrated favorable economics. For retrofit work these measures are much more costly to complete supporting the hypothesis that every effort should be made to incorporate energy-efficiency during design and construction to minimize the installed GHP system capacity.

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[27] For tight ducts and envelope testing is required for verification. In addition, proper duct and envelope sealing methods must be followed during construction to achieve improved performance.

6. Recommendations

Recommendations based on project results include:

1. SMUD and TDPUD should require the following for new GHP installations in their service territories: Manual J loads analysis, Manual D duct design, tight ducts (contractor or third-party verified), and a system commissioning report completed by the installing contractor. These steps will go a long way to insuring that installed systems meet the design intent.

2. SMUD should investigate GHP feasibility on a multi-family project, particularly if natural gas is not available. Multi-family with central water heating could offer improved economics, since year-round DHW loads will contribute to ground loop downsizing in cooling-dominated applications. A student housing project at the University of California at Davis completed in 2000 incorporates GHP water heating and space conditioning.

3. Both utilities should determine if a more favorable electric rate could be offered to GHP customers. Rising electric rates relative to gas, especially in SMUD service territory, severely hampers GHP economics.

4. SMUD and TDPUD should work with the remediation site homeowners over the next few years to gather more data on the remediation benefit. A followup survey in two years and utility bill analysis would be beneficial in further understanding remediation benefits.