ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

A Comprehensive, High Efficiency Solution for Water Heating in Multifamily Buildings

June 2024 | CEC-500-2024-054

PREPARED BY:

Abdullah Ahmed
Tim Krause
Energx Controls, Inc.
Primary Authors

Amir Ehyai
Project Manager
California Energy Commission

Agreement Number: PIR-16-005

ACKNOWLEDGEMENTS

The authors thank Equity Residential, Tecogen, ergSol, Negawatt Consulting, the technical advisory committee, local businesses, Southern California Gas Company, and many other industry professionals for financial, engineering, and technical support for this project. The authors are grateful to the California Energy Commission for guidance and support throughout the project.

The research team gratefully acknowledges the funding received from the California Energy Commission and Equity Residential in support of this research.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

A Comprehensive, High Efficiency Solution for Water Heating in Multifamily Buildings is the final report for Contract Number PIR-16-005, conducted by Abdullah Ahmed and Tim Krause of Energx Controls, Inc. The information from this project contributes to the Energy Research and Development Division's Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

Residential dwellings in California use 4,119 million therms of fossil gas of which 19 percent is used by multifamily homes. Fossil gas energy used in domestic hot water production accounts for 33 percent of the total multifamily fossil gas use. It is estimated that about 50 percent of the multifamily apartment buildings use central gas water heaters.

Recent emerging technologies such as the gas-engine heat pump can have a significant impact in reducing fossil gas consumption in central water heating applications because their coefficient of performance can be as high as 2.0, versus the conventional gas water heater thermal efficiency of 82 to 85 percent. Another emerging technology is the evacuated tube solar collector, a new type of solar thermal water heating collector with higher efficiency than the conventional flat plate collector.

This research and demonstration project used an integrated solution for water heating in a multifamily central water heating setting with a gas-engine heat pump and a scalable evacuated tube collector solar thermal array. They were used to assess the performance of the integrated solution and validate the research hypothesis that such as solution can cost effectively reduce domestic hot water energy consumption in multifamily buildings by 75 percent. Research demonstrates that optimal performance of the gas-engine heat pump is critical for achieving these goals. Successful application (50 percent adoption) of these technologies in California by multifamily buildings could save 99.18 million therms annually and reduce emissions of greenhouse gases by 580,200 tons and nitrogen oxides by 55 tons.

Keywords: gas engine heat pump, GEHP, GHP, evacuated tube solar collector, domestic hot water, DHW, multifamily water heating

Please use the following citation for this report:

Ahmed, Abdullah, and Timothy Krause. 2022. *A Comprehensive, High Efficiency Solution for Water Heating in Multifamily Buildings*. California Energy Commission. Publication Number: CEC-500-2024-054.

TABLE OF CONTENTS

Acknowledgements i

Preface ii

Abstract iii

Executive Summary 1

- Introduction 1
- Project Purpose 1
- Project Process 1
- Project Results 2
- Technology Transfer 2
- Benefits to California 3

CHAPTER 1: Introduction 4

CHAPTER 2: Project Research Hypothesis and Plan 5

- Project Goals and Objectives 5
- Project Benefits 5
- Demonstrated Technologies 5

CHAPTER 3: Project Outcome and Challenges 7

CHAPTER 4: Project Site Location 8

CHAPTER 5: Project Design 9

CHAPTER 6: Measurement and Verification 11

- Overall Measurement & Verification Approach 11
- Data Points and Instrumentation 11
- M&V Results 11
  - Baseline System 11
  - Retrofit System 13

CHAPTER 7: Project Construction 18

- Permits & Inspections 18
- Construction 18

CHAPTER 8: Project Start-up and Troubleshooting 19

CHAPTER 9: Economic Analysis 20

- Assumptions 20

CHAPTER 10: Technology Transfer 23

CHAPTER 11: Benefits to State of California 25

CHAPTER 12: Conclusions 27

Glossary and List of Acronyms 28
References 30
Appendix A: Technology Descriptions A-1
Appendix B: Project Plans B-1
Appendix C: Measurement and Verification (M&V) Report C-1

LIST OF FIGURES

Figure 1: Picture of the Park West Apartments 8
Figure 2: Boilers and Storage Tank on the Roof 9
Figure 3: New DHW Schematic 10
Figure 4: Daily Average Boiler Efficiency 13
Figure 5: Daily Average GEHP COP (Retrofit Period) 14
Figure 6: Daily Average Temperatures at the GEHP Plant (Retrofit Period) 15
Figure 7: Daily GEHP Gas Usage, GEHP Heat Output, and Solar Thermal Heat Output (Retrofit Period) 15
Figure 8: Daily Average GEHP COP (Retrofit Period) 17
Figures A-1 and A-2: Ilios Heat Pump A-1
Figure A-3: Outdoor Air Temperature Versus Heat Output A-2
Figure A-4: Outdoor Air Temperature Versus COP A-2
Figure A-5: Evacuated Tube Performance A-4
Figure A-6: Evacuated Tube Collector A-4
Figure A-7: Energx Raydronics Boiler Controller A-5
Figure A-8: Monitored Boiler Temperature A-5
Figure B-1: Engineering Plans for the Domestic Hot Water System Upgrade at Park West Apartments B-1
Figure B-2: Los Angeles Department of Building and Safety Application for Building Permit and Certificate of Occupancy B-12
Figure C-1: Baseline M&V Instrumentation Installation Guidance Diagram C-6
Figure C-2: Baseline & Retrofit M&V Instrumentation Diagram C-6
Figure C-3: Existing Boilers and Storage Tank C-7
Figure C-4: Existing Storage Tank Water Piping and Boiler Gas Piping C-8
Figure C-5: Boiler Nameplate C-8
Figure C-6: October 2018 Gas Utility Bill C-9

Figure C-7: Gas Usage versus Dry Bulb Temperature C-10
Figure C-8: Daily Boiler Gas Usage and Boiler Net Heat Output to Tank C-12
Figure C-9: Daily Average Boiler Efficiency C-12
Figure C-10: Daily Water Volumes C-13
Figure C-11: Daily Thermal Energy C-14
Figure C-12: Daily Boiler Gas Usage C-14
Figure C-13: Daily Average Temperatures C-15
Figure C-14: Daily Average Temperature Deltas C-15
Figure C-15: GEHP Gas Usage versus Dry Bulb Temperature (Retrofit Period) C-16
Figure C-16: Boiler Gas Usage versus Dry Bulb Temperature (Retrofit Period) C-17
Figure C-17: Total Gas Usage versus Dry Bulb Temperature (Retrofit Period) C-17
Figure C-18: Daily GEHP Gas Usage, GEHP Heat Output, and Solar Thermal Heat Output (Retrofit Period) C-19
Figure C-19: Daily Average GEHP COP (Retrofit Period) C-19
Figure C-20: Daily Average Temperatures at the GEHP Plant (Retrofit Period) C-20
Figure C-21: Daily Water Flow through the GEHP and Solar Thermal (Retrofit Period) C-20
Figure C-22: Daily Boiler Gas Usage and Boiler Net Heat Output to Tank (Retrofit Period).. C-21
Figure C-23: Daily Average Boiler Efficiency (Retrofit Period) C-21
Figure C-24: Daily Boiler Gas Usage (Retrofit Period) C-22
Figure C-25: Daily Average Temperatures at Boiler Plant (Retrofit Period) C-22
Figure C-26: Daily Average Temperature Deltas at Boiler Plant (Retrofit Period) C-23

LIST OF TABLES

Table 1: Estimated Baseline Annual Values 12
Table 2: Estimated Retrofit Annual Values 14
Table 3: Estimated Retrofit Annual Values by Equipment Type 16
Table 4: Summary of Economic Analyses 21
Table 5: Calculation of Benefit/Cost Ratio 21
Table 6: GHG Emissions & Reduction 22
Table 7: Annual Energy & Emissions Calculations 25
Table A-1: Comparison Performance A-3

Executive Summary

Introduction

The multifamily market has been the slowest in adopting emerging energy efficiency technologies. This is due to lack of technologies in the marketplace and a lack of service providers. Domestic hot water boiler and water heater technologies have hit the limit of their efficiency with non-condensing efficiencies of 80 to 82 percent and condensing efficiencies of less than or equal to 98 percent; thus limiting the potential for deep energy savings in water heating. The demonstration of an integrated technology solution using evacuated tube collector solar thermal collector array with a gas engine heat pump along with advanced control could significantly reduce energy consumption in apartment buildings.

This project demonstrated the integrated and comprehensive solution in a multifamily building. The site is Park West Apartments, owned and operated by Equity Residential and located in Los Angeles, California. The solution combines advanced solar thermal water heating using evacuated tube technology from ergSol with a Ilios fossil Gas-Engine Heat Pump manufactured by Tecogen and the Energx-developed central water heating loop controller for central water heating. The existing boiler system consists of two 750,000 British thermal unit boilers and a storage tank on the roof serving domestic hot water to 144 apartments.

By demonstrating and documenting the performance of advanced technologies in water heating and improved hot water distribution controls, the project team hoped to help proliferate these technologies, build awareness among multifamily building owners and operators, and the use of fossil gas and the associated emissions.

Project Purpose

The primary goals and objectives of this project were to demonstrate an integrated solution for achieving at least a 75 percent reduction in fossil gas use in domestic hot water heating, understand how the combination of technologies can be optimized to deliver deep energy savings and investigate the performance and cost effectiveness of each of the subsystems (evacuated tube technology and gas-engine heat pump) operating independently. Then build awareness through outreach efforts among multifamily property owners of the comprehensive solution to help create the market.

Project Process

The project team consisted of Energx Controls as the principal investigator, Mission Aire as the installing contractor, Occidental Analytical Group as the project engineering designer and field coordinator, and Negawatt Consulting as the measurement and verification entity. The project approach included initial meetings with building maintenance to get their support and energy monitoring of the building domestic hot water system to establish baseline water heating energy use and water use. This was followed by installation of the evacuated tube solar collectors with storage tank, gas engine heat pump and integration of controls with existing water heater, and observation of the performance of the integrated system component by component to evaluate peak performance and overall effectiveness. Then, 12 months of data collection through an independent measurement and validation study, followed by savings and cost/benefit analysis. Finally, outreach efforts were conducted to build awareness of the technology among industry partners and to inform utility stakeholders on how they could support the technology for further proliferation through energy efficiency programs.

Project Results

Pre-installation measurement and verification and subsequent construction phases were successfully executed with some delays. The pre-installation measurement and validation resulted in about 10,800 therms per year in water heating. This did not agree with the average of 16,400 therms per year calculated from utility bills.

Several scenarios of economic analyses were done, including analysis of the baseline operation with the existing boilers. Economic analysis of the gas-engine heat pump operating alone was done based on the measured coefficient of performance of 1.05, as well as the rated or expected coefficient of performance of 2.0. Then the same analysis was done with a 20-panel solar thermal array added to the gas-engine heat pump. Finally, an analysis was done based on a 100 percent satisfaction of domestic hot water load by the solar array alone. In sum, six different scenarios were analyzed.

The project team performed life cycle analysis, simple pay back analysis, and annualized costs of the six alternatives. The results show that the replacement cost of the existing boiler system which is near its end-of-life is $101,500. The annual fuel energy cost is $26,093 based on the average utility bills. If the gas-engine heat pump operates at a coefficient of performance of 2.0, the system has a simple payback of five years and with a solar array of 20 panels, the simple payback can be 10 years. This indicates that both the individual gas-engine heat pump or the integrated system could be eligible for utility incentives and subsidies to get market adoption and become cost competitive in the future. The results also indicate that installation of 100 percent solar thermal will require about 140 evacuated tube collectors at a cost of $422,400 and a simple payback of 12 years. If the gas-engine heat pump can deliver a minimum coefficient of performance of 2.0, the annualized cost of operation will be lower than the baseline system.

The analyses also included annual greenhouse gas emissions of each alternative and cost benefit ratio calculations. Detailed results are presented in Chapter 9 of this report.

Technology Transfer

The demonstrated technologies are not limited just to multifamily buildings. If the integrated solution is commercialized, it could provide a low emission, low energy source of hot water for several commercial/industrial customers in most California climate zones.

The scalability of the evacuated tube solar collector system allows the gas-engine heat pump to be installed in facilities that use large amounts of hot water such as in hotels, commercial laundries, food processing, prisons, large restaurants, and hospitals. The only challenge is the required physical space for the applications. Solar thermal collectors compete for roof space with solar photovoltaic collectors and the gas-engine heat pump and associated storage tank require additional space near the existing domestic hot water system.

Outreach and communication materials include fact sheets, journal articles, participation in conferences, and public dissemination of the final report.

Benefits to California

Through the demonstration of this project the research team hoped to increase awareness of the comprehensive solution, and demonstrate a cost-effective approach to reduce energy use, costs, and greenhouse gas emissions in domestic hot water heating.

Reduced energy use will improve energy security and enhance customer maintenance, repair staff, and building tenant appreciation.

Implementation of the integrated technologies will create jobs for multiple disciplines including plumbers, pipe fitters, riggers, electricians, mechanics, solar installers, and controls technicians. If successful, with proper policy, regulations, and incentives, market adoption of the technology will increase in the future with thousands of jobs created. Reduction of greenhouse gases and nitrous oxide emissions will contribute directly to public health, which aligns with the policy goal of the South Coast Air Quality Management District and the California Air Resources Board.

CHAPTER 1: Introduction

The multifamily market has been the slowest in adopting emerging energy efficiency technologies due to lack of technologies in the marketplace and a lack of service providers. Domestic hot water (DHW) boiler and water heater technologies have hit the limit of their efficiency with non-condensing efficiencies of 80 to 82 percent and condensing efficiencies of up to 98 percent, thus limiting the potential for deep energy savings. This research and demonstration project used a solution that combined advanced solar thermal collector water heating using evacuated tube collector (ETC) technology with emerging fossil gas-engine heat pump (GEHP) for central DHW in a multifamily apartment building. Also planned was the inclusion of the Energx-developed central water heating loop controller. This integrated system could achieve deep energy savings, and reduced greenhouse gas (GHG) and nitrous oxide (NOx) emissions.

CHAPTER 2: Project Research Hypothesis and Plan

It was hypothesized that installation of a GEHP that is integrated with an ETC solar thermal system could be cost effective due to reduced energy use and reduced emissions over a conventional boiler system for domestic hot water in multifamily buildings.

The key feature was to integrate a GEHP with advanced evacuated tube solar thermal collectors as the secondary heat source. The pre-existing central water heater was to remain in place as a back-up system. The project team anticipated a reduction of the total water heating energy use by more than 75 percent. The GEHP system was expected to use 50 percent less energy than the existing boilers and an additional 10 to 15 percent of savings was to be delivered by the scalable solar thermal system. Included in the effort was the Energx-developed hot water controller that has been shown to reduce line losses. The installation was expected to result in a significant fossil gas savings and a reduction of associated emissions within the South Coast Air Quality Management District (SCAQMD) air basin.

Project Goals and Objectives

The purpose of this project was to demonstrate an integrated high efficiency solution to achieve at least a 75 percent reduction in fossil gas use and emissions in DHW heating. The primary goal was to investigate how the combination of technologies could be optimized to work in unison to deliver deep energy savings and emission reductions. The research team investigated the performance and cost effectiveness of each of the subsystems (ETC and GEHP) operating independently and conducted cost effectiveness analyses for potential viability as a future utility energy efficiency incentive measure or considerations to inform future code standards.

Project Benefits

The research goal was to identify benefits to the multifamily property owners, as well as the State of California, and California utility ratepayers. Through the demonstration of this project, the project team hoped that the customer would experience the benefits of reduced fossil gas use for water heating, and reduced GHG and NOx emissions. The team would build increased awareness of the comprehensive solution among multifamily building operators. Benefits to the State of California and its ratepayers and residents would be lower costs, greater reliability with energy security, increased safety, economic development, and environmental benefits with improved public and consumer appeal of the technologies.

Demonstrated Technologies

The project demonstrated two technologies that reduce fossil gas energy use in water heating. They are the ETC and GEHP. A third technology, the Energx dual setpoint controller did not get installed because the troubleshooting of the GEHP took an inordinate amount of time.

The ETC consists of several sealed glass tubes that have a thermally conductive copper rod or pipe inside allowing for much high thermal efficiency, even during a freezing day, and working temperature compared to the flat plate solar collectors.

Gas-engine-driven heat pumps offer an economic alternative to gas water heaters and boilers and an outstanding opportunity to reduce water heating costs and lower GHG emissions. Advances in internal combustion engine technology have led to significant improvements in reliability and efficiency of the GEHP with operating life exceeding 20,000 hours. Additionally, new emissions control technology has led to fewer emissions and lower criteria pollutants.

The Energx dual setpoint controller is an energy savings controller that reduces the water temperature setpoint when hot water is not required. The savings are primarily achieved by controlling the setpoint temperature of the water in the storage tank and by controlling the firing rate of the boiler, since these boilers typically have three to four burners staged in series to meet various load changes.

Of the three technologies, the Energx dual setpoint controller was not installed at the project site due to cost overruns associated with project execution delays, COVID-19 pandemic delays, and technology troubleshooting. These technologies are further described in Appendix A.

CHAPTER 3: Project Outcome and Challenges

Project outcome has been a mixed bag of results, with the goals being partially met. There were unexpected turns during project execution that significantly impacted the project.

A GEHP traditionally consists of a vapor-compression refrigeration cycle that includes a condenser, an evaporator, a throttling valve, and a compressor. Compressor shaft work is provided by a reciprocating engine. Depending on the operating conditions, the Ilios GEHP's coefficient of performance (COP) is between 1.2 and 2.2. For this project, the team expected a COP of around 2.0. However, the measured COP was notably less at 1.05. Representatives of Tecogen worked diligently with the project team to get to the root of the problem. The team hoped the manufacturer would identify and take corrective action to improve the COP to be at least 1.6 or higher. The second unexpected turn of event was the COVID-19 pandemic, which hit the project just as the system start-up and shakedown was beginning. This resulted in a more than one year delay.

The measurement and verification (M&V) phase of this project had its challenges as well. The site uses one gas meter that serves the entire building and includes three DHW plants, a pool, and other gas-fired equipment and appliances. This project involved the retrofit of one of the three DHW plants. The calculated pre-installation M&V results showed that the boiler system annual energy use was 10,837 therms. This figure is much lower than the three-year average consumption of 16,400 therms/year based on utility bills. Furthermore, the post installation M&V showed higher consumption of fossil gas than the baseline due to high line losses in the uninsulated pipe risers within the building, which were not physically accessible, and perhaps due to the change in occupancy and occupant behavior in using hot water due to the COVID-19 pandemic. Also, with the low GEHP COP, the solar thermal alone could not meet the load, therefore, the existing boilers were also working, resulting in higher gas use.

Economic analysis with monitored COP of 1.05 and a target COP of 2.0 shows that the net present value (NPV) of the costs of the installed GEHP is lower than that of the replacement cost of the existing DHW system. Simple payback of the GEHP system is six years. However, the integrated system of the GEHP and ETC solar thermal system is not cost effective in multi-family applications.

Notwithstanding these issues, the project team can take satisfaction that the project was a success from the construction point of view and could have been a showcase, had the performance of the GEHP met the expected COP.

The GEHP start-up has been an arduous journey. The final issue yet to be resolved is whether the GEHP has some inherent production flaws in the compressor operation, condenser tubing, internal heat exchanger or other control issues that is causing the low COP. Tecogen had been investigating the issue, but could not come to a firm conclusion.

CHAPTER 4: Project Site Location

Project site is Park West Apartments, owned by Equity Residential, located at 9400 La Tijera Boulevard, Los Angeles, California. The property's older boilers would need replacement within two years. GEHP could eliminate that requirement with substantial capital investment savings for Equity Residential. Figure 1 is photograph of the Park West Apartments.

Figure 1: Picture of the Park West Apartments

Source: Equity Residential

Park West Apartments consists of 441 apartment units in a four-story building with two garage levels. There are three boiler systems serving the apartments. Each system consists of two 750,000 British thermal unit (Btu) boilers with a 250-gallon storage tank serving 147 apartments. The systems are located on the roof. It was determined that the GEHP and storage tank could not be installed on the roof because it is a light-weight roof. The most optimal location for the system was determined to be in a vacant room on the ground floor of the garage near the entrance to the garage from Lincoln Avenue. This location is near the site's city water service, the hot and cold-water loop, and a two-inch natural gas pipe that serves the BBQ and pool equipment.

CHAPTER 5: Project Design

The plumbing system in the Park West Apartments consists of three different boiler systems serving the 441 apartments, with a single system serving 147 apartments. The research project impacted only one of the three systems. The building is an "L" shaped four-story building with a flat roof and a bi-level garage of which one level is on the street level and other level is subterranean. Each hot water system consists of two boilers with a single storage tank, all located on roof (Figure 2). All the plumbing services (sewer, domestic cold water, domestic hot water, hot water recirculation loop, high- and low-pressure fossil gas) are installed as headers along the ceiling of the street level of the garage (below the first-floor slab). Figure 2 shows one of the typical roof-top boiler installations.

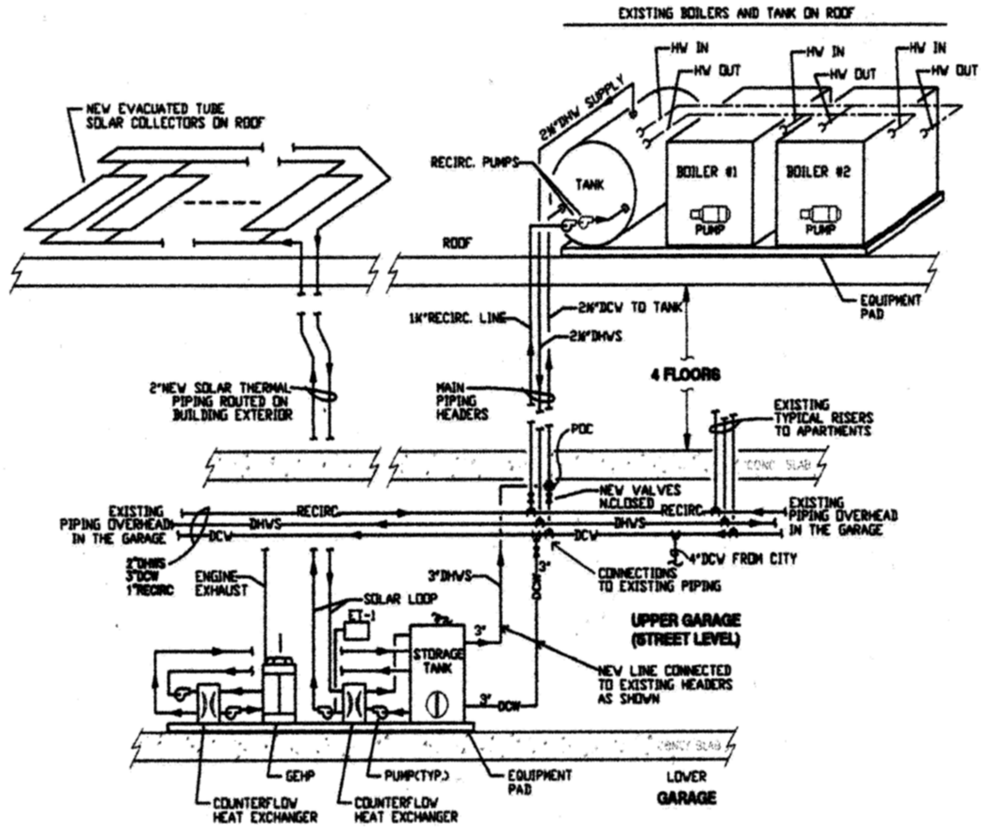
Figure 2: Boilers and Storage Tank on the Roof

Source: Equity Residential

All along the garage, there are risers from the headers for hot water, cold water, and sewer. The hot water piping from the storage tank on the roof and the hot water recirculation pipe come down and connect to the DHW supply and recirculation headers. The domestic cold water from the header runs up to the storage tank on the roof. The boiler pumps draw water from the storage tank into the boilers and deliver hot water into the tank.

Figure 3 is a schematic diagram showing how the piping of the new equipment was integrated into the existing plumbing system in Park West. The hot water discharge from the new storage tank in the garage, intercepts the domestic cold-water riser to the storage on the roof, with a new valve to separate the piping from the domestic cold-water piping. The city water is then diverted into the new storage tank. By doing this, the hot water piping from the new storage tank to the existing storage tank header on the roof can be eliminated, saving a lot of piping. This schematic also shows the new solar collector piping, plate-and-frame heat exchangers, the GEHP, the pumps, and the large 450-gallon storage tank. Appendix B includes the approved project plans and permits.

Figure 3: New DHW Schematic



DOMESTIC HOT WATER SYSTEM SCHEMATIC INCORPORATING SOLAR THERMAL COLLECTORS AND GAS ENGINE HEAT PUMP (GEHP)

Source: Occidental Analytical Group

CHAPTER 6: Measurement and Verification

Overall Measurement & Verification Approach

The goal of the project M&V was to assess the overall energy savings potential of the retrofitted equipment, controls hardware, and controls strategies as compared to the baseline DHW system at the test site.

The gas to the existing boilers, and new GEHP, were measured by diaphragm gas meters with pulse output. Pump power for the new pumps was measured with three-phase power meters. Heat energy into and out of the existing storage tank, and out of the GEHP was measured with Btu meters. Data was typically sampled at one-second intervals and saved at one-minute intervals.

The two boiler gas meters, and the one Btu meter between the boilers and the existing storage tank, were used to estimate the COP of the pair of existing boilers at an hourly interval for time periods of consistent data. The GEHP gas meter and Btu meter were used to estimate the COP of the GEHP at hourly intervals for time periods of consistent data.

For each measurement period, to search for a linear correlation, the gas usage was aggregated into daily intervals and scatter plotted in comparison to daily weather station dry bulb temperature. Normalization for other factors such as occupancy was not conducted, and pump energy was not scatter plotted against any factors.

Correlation was not great for either period, but both gas versus the dry bulb temperature trendline equation were nevertheless applied to California Climate Zone typical weather data. This yielded estimated annual energy usage for the baseline and retrofit periods as well as estimated annual savings.

Data Points and Instrumentation

A data points and instrumentation list, along with the baseline and retrofit M&V monitoring and instrumentation diagrams and data points, recording intervals, and accuracy are included in Appendix C, which contains the M&V report.

M&V Results

The results of the M&V effort are presented in the following sections.

Baseline System

Measurements gave insight into the plant’s operation. The boiler pumps run at a flow rate of approximately 90 gallons per minute (gpm); the boiler supply to return water temperature difference is typically less than six degrees Fahrenheit (°F) (-14 degrees Celsius [°C]); and the tank supply temperature setpoint is easily met. This indicates that cycling the pumps with a call for heat would be more efficient and that one boiler is redundant (i.e., one boiler has sufficient capacity to satisfy the load).

The hot water supply temperature is approximately 130°F (54°C) and the return water temperature is typically about 6°F (-14°C) colder. The recirculating water pumps run constantly at a steady combined flow rate of approximately 19 gpm. The average minutely hot water draws are typically less than 10 gpm and often less than 5 gpm. This indicates that the recirculating water pump flow rate could be reduced without impacting hot water wait time at the fixtures, and that the recirculating water loop heat loss is a substantial portion of the current load. The team used metered gas consumption in cubic feet, and corrected for elevation, pressure delivery and a calculated the therm factor to convert the volume of gas used to its heat equivalent.

Applying a trend-line equation to daily outside air temperature data for California Climate Zone 6, yielded 10,837 therms/year in DHW use as shown in Table 1. Associated GHG emissions are shown using the California Energy Commission's (CEC's) emissions factor of 11.7 pounds (lbs.) of carbon dioxide (CO_2) equivalent (CO_2e). Gas cost was calculated using CEC's statewide average residential rate of $1/therm.

Table 1: Estimated Baseline Annual Values

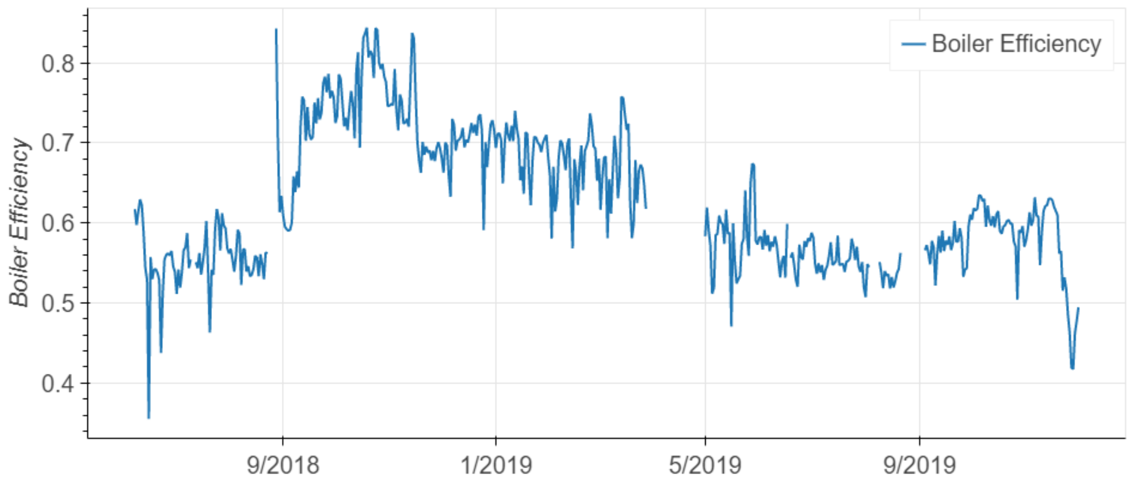
Baseline Annual DHW Gas Usage [therms]	Baseline Annual DHW Gas Usage [MMBtu]	Baseline Annual DHW Gas Cost [$, Statewide Average]	Baseline Annual CO_2e from DHW Gas Usage [lbs.]	Date Range
10,837	1,084	$10,837	126,792	6/8/18-12/1/19

Source: NegaWatt Consulting

That baseline annual DHW gas usage is much lower than the three-year average consumption of 16,400 therms/year from utility bills. The site has one master meter and the usage in those bills serves all three DHW plants at the site, each of which serves 147 residential units and one of which is part of this project. The meter also serves all the gas dryers in the building, the pool heating, and the heating of two spas. To obtain the estimate of 16,400 therms/year, it was assumed that all three DHW plants consume the same amount of gas, and industry averages were used for dryers, pool, and spas. The discrepancy between the M&V-based estimate and the utility bill-based estimate could be due to multiple factors. First, gas pressure was not measured at the gas utility meter or at the gas meters at the boilers. The impact is likely small because the utility, SoCalGas, likely estimated the correct gas pressure and therefore therms at the gas utility meter, and the gas pressure estimate for the boilers is likely fairly accurate due to the gas pressure requirements of the boilers. Second, there is a chance that the gas meters and related instruments at the boilers somehow didn't record the proper gas volume. Third, perhaps the assumptions described above for all the other equipment on the gas utility meter have inaccuracies.

Figure 4 shows average boiler efficiency, which is net boiler output divided by boiler gas input. The net output data was from the Btu meter across the boiler supply and return pipes between the boilers and the storage tank, and the input data was from our gas pulse measurements. It is not clear what caused the spike in boiler output in late August 2018. The drop in boiler output in late October 2018 coincides with a drop in hot water draws. The gradual increase from September 2018 to early 2019 correlates with colder ambient temperatures which increases boiler load during water draws. The improved efficiency seems to indicate that the boilers are oversized.

Figure 4: Daily Average Boiler Efficiency



Source: NegaWatt Consulting

This plot shows the boiler efficiency as a timeseries line plot from June 8, 2018 to December 1, 2019 and ranged from about 0.36 to 0.84. The efficiency is spikey, but it generally increases until about 10/2018 and then generally decreases after that.

Retrofit System

Retrofit System Conditions

The retrofit system consists of the GEHP and solar thermal systems which both pre-heat the cold-water makeup water going to the existing DHW system. The project team did not otherwise modify the existing DHW system whereas the site staff did make seasonal control changes and dealt with some pump and boiler failures. System instrumentation including gas flow measurement into the GEHP, inlet and delivered water flows and temperatures for both the GEHP and the solar thermal loops pumps were monitored but electric energy use or efficiency were not a part of the project. As far as the retrofit equipment, the GEHP system had much lower equipment COP than expected but functioned properly otherwise.

The project team applied a trend-line equation to daily outside air temperature data for California Climate Zone 6, which yields 20,926 therms/year according to Table 2. Associated GHG emissions are shown using CEC's emissions factor of 11.7 pounds of CO_2e per therm. Gas cost is shown using CEC's statewide average residential rate of $1/therm.

Table 2: Estimated Retrofit Annual Values

Retrofit Annual DHW Gas Usage [therms]	Retrofit Annual DHW Gas Usage [MMBtu]	Retrofit Annual DHW Gas Cost [$, Statewide Average]	Retrofit Annual CO_2e from DHW Gas Usage [lbs.]	Date Range
20,926	2,093	$20,926	244,837	6/1/20-4/11/21

Includes GEHP and Boiler Gas Usage. Additional electrical usage for new pumps not addressed.

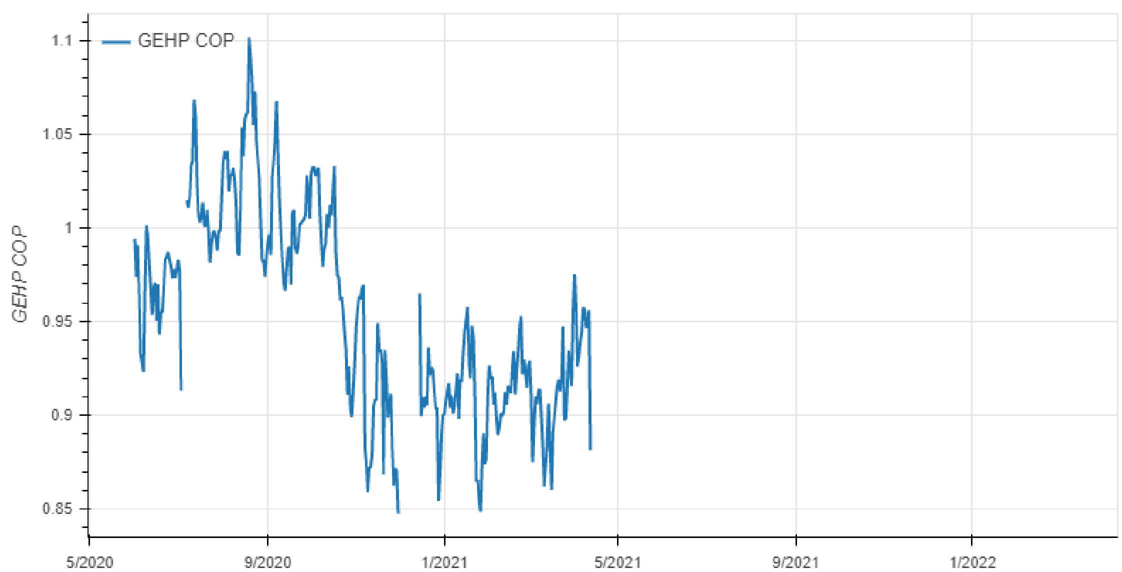
Source: NegaWatt Consulting

Additional Retrofit M&V Results

The figures below show the primary data collected during the retrofit period at the new GEHP plant and the existing boiler plant. There was some missing data when Modbus communication with the GEHP equipment and related sensors was lost in mid-April 2021.

An important finding during the retrofit period was that the GEHP COP was lower than expected (Figure 5). The manufacturer and project team attempted multiple fixes.

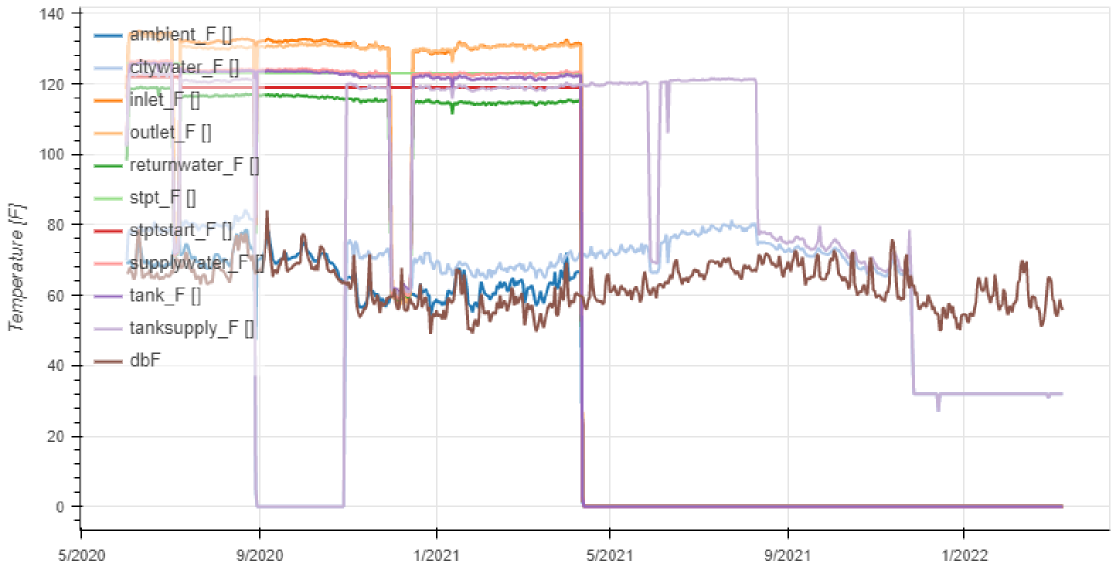
Figure 5: Daily Average GEHP COP (Retrofit Period)



Source: NegaWatt Consulting

Another important finding is that the retrofit energy usage was much higher than the baseline energy usage. However, it is clear from the temperature data that the GEHP and solar thermal system preheated the supply water as designed (see "tank_supply_F" and "citywater_F" in Figure 6). We expect that at least some of the gas usage increase was due to COVID-19 impacts. Surprisingly, gas bills from the project site indicate that overall yearly site gas usage was steady from 2018 through 2020.

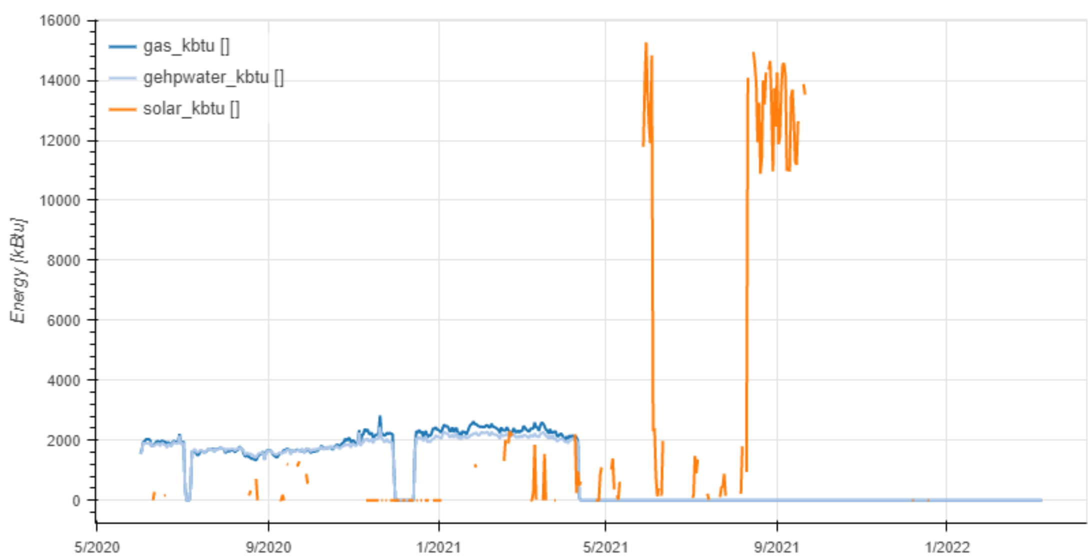
Figure 6: Daily Average Temperatures at the GEHP Plant (Retrofit Period)



Source: NegaWatt Consulting

The solar thermal system heat output is compared to the GEHP heat output in Figure 7. There are only a few data points for the solar thermal system because anomalous temperature data was removed. The average ratio of solar thermal system heat output to GEHP heat output for days where there was useable non-zero data for each was 66 percent (i.e., the solar thermal system provided 66 percent as much heat output as the GEHP system on average when both systems were operational and M&V data was available). There were 47 such observations. The same figure also indicates that the solar thermal system can output significantly more energy when the GEHP system is not running. This is because it works better when the inlet water is colder.

Figure 7: Daily GEHP Gas Usage, GEHP Heat Output, and Solar Thermal Heat Output (Retrofit Period)



Source: NegaWatt Consulting

In Table 3 below, calculations are presented for the GEHP, boilers, and, to a lesser degree, the solar thermal system. The solar thermal system "annual gas usage" represents the rough amount of additional GEHP gas usage that would have been required if the solar thermal system were not there. It is calculated more roughly than the GEHP and boilers given that there are less usable observations of the system. The solar thermal system annual gas usage is simply estimated as 51 percent of the GEHP annual gas usage. The calculation of that percentage is described later and the GEHP COP is assumed to be 1.

Table 3: Estimated Retrofit Annual Values by Equipment Type

Equipment Type	Retrofit Annual DHW Gas Usage [therms]	Retrofit Annual DHW Gas Usage [MMBtu]	Retrofit Annual DHW Gas Cost [$, Statewide Average]	Retrofit Annual CO_2e from DHW Gas Usage [lbs.]
GEHP	7,599	760	7,599	88,904
Boilers	13,328	1,333	13,328	155,933
Solar Thermal	3,875	388	3,875	45,341

Source: NegaWatt Consulting

The solar thermal system "Retrofit Annual DHW Gas Usage [therms]" represents the rough amount of additional GEHP gas usage that would have been required if the solar thermal system were not there. Also, the pump electrical usage is not addressed.

Savings Estimate

Gas usage was higher during the retrofit period, as compared to the baseline period, so gas savings are not reported.

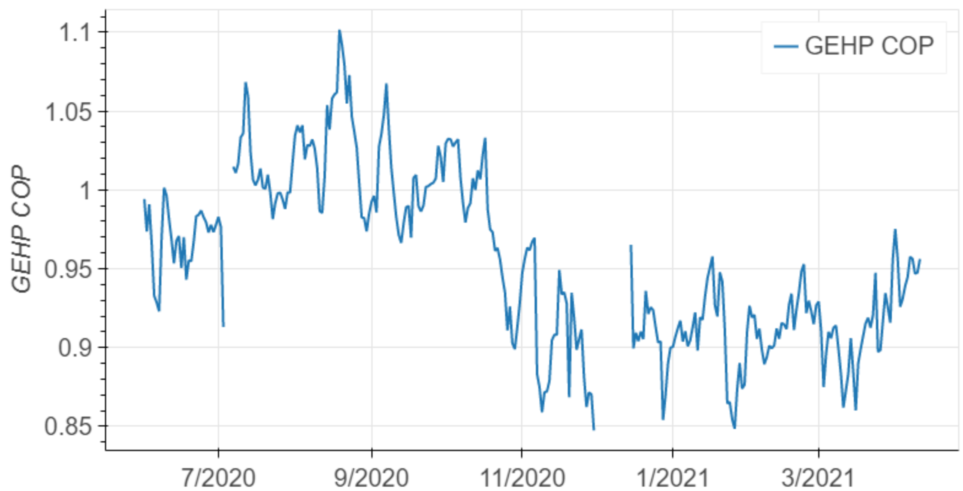
Several probable factors may have contributed to the higher gas use in the integrated system over the baseline system. They include:

- The domestic hot water load in the building was higher during the retrofit period versus the baseline period due to more people being at home during the COVID-19 pandemic.
- The two boilers typically operated in the retrofit period while one boiler typically operated during the baseline period due to on-site maintenance changing the boiler operation.
- The preheated makeup water line from the garage to the roof was not insulated. Comparing the garage tank temperature, to the cold make-up water temperature on the roof, shows a temperature drop of 20°F (-7°C). This heat loss had to be overcome by the existing boilers.
- The two existing hot water return pumps might have encountered failures or been reconfigured by the facility staff such that recirculation loop flow rate was different between the baseline and retrofit periods.

An important finding during the retrofit period was that the GEHP COP was lower than expected (Figure 8). The general spikiness of the data could be due to inherent inaccuracy in the M&V instrumentation. The significantly lower efficiency after about November 2020 might be due to several factors. The data indicates that the city water temperature was lower after November 2020 but that the solar thermal system and perhaps the boilers had more output. This may have caused the GEHP to experience less load and, therefore, be less efficient due to more short cycling. Also, perhaps there were GEHP equipment performance issues that were more prominent after November 2020.

There are only a few data points for the solar thermal system because anomalous temperature data was removed. The average ratio of solar thermal system heat output, to GEHP heat output, for days where there was useable non-zero data for each was 66 percent (i.e., the solar thermal system provided 66 percent as much heat output as the GEHP system on average when both systems were operational and M&V data was available). There were 47 such observations. The data also indicates that the solar thermal system can output significantly more energy when the GEHP system is not running. This is because it works better when the inlet water is colder.

Figure 8: Daily Average GEHP COP (Retrofit Period)



Source: NegaWatt Consulting

The plot in Figure 8 shows the GEHP COP as a timeseries line plot from June 1, 2020, to April 11, 2021, and ranges from about 0.85 to 1.1. The COP is generally spikey and significantly lower after approximately November 2020.

CHAPTER 7: Project Construction

Permits & Inspections

Appendix B presents the construction plans and contains the copies of all permits and final inspection card for the project. The project team had to secure several permits for the project. They included building plan check for structural and plumbing, plumbing and mechanical permits, solar thermal permit, and electrical permit.

Construction

Project construction was completed in three distinct phases. The first phase consisted of modifying the existing piping on the roof for the hot water and cold water to accommodate the M&V instrumentation for baseline monitoring. The second phase of construction began after project permits were issued by the city of Los Angeles. This included installation of the GEHP, pumps, storage tank, solar collectors, and piping and instrumentation. The third phase of the work involved system start-up and troubleshooting. Chapter 8 describes this step in detail. The entire construction effort took longer than six months.

CHAPTER 8: Project Start-up and Troubleshooting

The solar thermal system was started and was operating well, delivering 30 gpm of hot water to the heat exchanger. The delivery temperature varied between 120°F (49°C) to 160°F (71°C) depending on the storage tank temperature, weather, and the time of day. There were few, if any, issues with the solar system.

The project team encountered several issues on the operation of the GEHP, however. Recorded COP was around 1.05 when the expected COP was 2.0. The GEHP manufacturer, Tecogen, was able to observe the unit operation remotely and help diagnose its operational issues. A process of elimination was used to rule out reasons for GEHP performance issues.

After the initial shakedown was completed and corrective measures taken, Tecogen began to monitor the GEHP performance. The COP calculation indicated less than 1.0. Review of temperatures, gas flows, and refrigeration system indicated that the low COP was due to insufficient air flow across the evaporator coils. The required air flow is 22,000 cubic feet per minute (cfm). With only about 10,000 cfm of air flow across the coils, the project team then removed the ducts above the GEHP, and air flow improved to about 14,000 cfm, However, the COP did not increase. Per Tecogen requirements of 22,000 cfm, the project team then installed two in-line booster fans to increase air flow to 21,000 cfm. The COP improved to about 1.05.

Attention then moved to the engine and refrigerant compressor. If the system achieved the air flow specification and recorded a 1.05 COP, then the situation was clear that something was going on inside the GEHP refrigeration cycle. The evaporator appeared to be performing well and the condenser data looked good. However, the data from the compressor was concerning. Field data was run through the performance modeling software, and it was believed that the compressor was not operating correctly. The concern was that the compressor valves were not sealing correctly, or that there were some other internal issues. The next step was to see if Tecogen would dismantle the engine-compressor. Mission Aire believed that there could be blockage of the refrigerant in the condenser, or the compressor valves could be damaged.

CHAPTER 9: Economic Analysis

Economic analyses of the project were done from the perspective of life cycle cost, simple payback, and annualized cost. In addition, annual GHG emissions and NOx emissions were calculated for each of the alternatives. Several scenarios of economic analyses were done, including the baseline operation with the existing boilers. Economic analysis of the GEHP operating alone was done based on the measured COP of 1.05 as well as the rated or expected COP of 2.0. Then the same analysis was done with a 20-panel solar thermal array added to the GEHP. Finally, an analysis was done based on 100 percent of DHW load using only solar. In sum, six different scenarios were analyzed. It was assumed that the entire water heating load was met by each of the alternatives.

Assumptions

As Chapter 6 indicates, the M&V of the baseline energy and the project technologies did not agree with the utility bills. The reasons could be several factors described earlier. Therefore, the baseline energy used was 16,420 therms/year, the estimated average of the last three years (2018 to 2020), instead of the calculated baseline from M&V (10,000 therms/year), which was low.

Equipment costs were determined from project equipment and installation costs. All labor costs were assumed to be at market pricing, not using prevailing wages. It is assumed that Equity Residential would have to replace the existing boilers. Therefore, the baseline alternative assumed boiler replacement but does not include the replacement of the existing storage tank. The new GEHP technology's installed cost was lower than the project's installed cost because it was assumed that the new technology would be co-located close to the existing system, unlike the project at Park West where the system is located on the first-floor garage and the intertie to the existing system is on the roof. This arrangement required extensive piping. In addition, the solar system installed on the roof also required long distances of piping and insulation.

The utility cost was hard to estimate because the Southern California Gas Company Rate Schedule gas meter was revised on March 10, 2022. Historical gas meter rates were around $1/therm, the new baseline rate is $1.38408/therm, and the non-baseline rate is $1.79798/therm. Without being able to forecast what portion of the bill would be under non-baseline consumption, the project team used an average rate of $1.59103/therm for the study.

Equipment life was assumed to be 15 years with zero salvage value. The 15 years used for the life cycle analysis is in line with American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) estimates of commercial heating, ventilation, and air conditioning/plumbing equipment. The analysis discount rate used is 8 percent, which is indicative of a higher risk associated with new technology.

As indicated in Chapter 8, the measured COP of the GEHP is around 1.05. Therefore, two scenarios of GEHP were analyzed, the tested COP of 1.05 and a rated COP of 2.0. The existing baseline boiler thermal efficiency, as measured through M&V, was 0.75 while the rated efficiency is 0.82. In the analysis, an efficiency of 0.8 for newer boiler efficiency was used.

The results of the analysis are summarized in Table 4 below:

Table 4: Summary of Economic Analyses

Summary of Economic Analyses										
Option			Installed	Incremental	Maint.	NG Energy	Annual Energy	Simple Pay	NPV of	Annualized
			Cost $	Cost $	Cost $/Yr	Use Th/Yr	Cost $/Yr	Back Yrs	LC Costs $	Cost $/Yr
Baseline Operation(replacement)			$ 101,500	$ -	$ 2,200	16,420	$ 26,125	N/A	$ 343,945	$ 40,183
GEHP COP 1.05			$ 186,000	$ 84,500	$ 8,000	11,729	$ 18,661	11	$ 414,200	$ 48,391
GEHP COP 2.0			$ 186,000	$ 84,500	$ 8,000	6,158	$ 9,797	5	$ 338,331	$ 39,527
GEHP COP 1.05 +Solar TH (20 Panels)			$ 271,000	$ 169,500	$ 11,000	10,556	$ 16,794	18	$ 508,906	$ 59,455
GEHP COP 2.0 +Solar TH (20 Panels)			$ 271,000	$ 169,500	$ 11,000	5,542	$ 8,817	10	$ 440,624	$ 51,478
Install 100% Solar Thermal			$ 422,400	$ 320,900	$ 18,000	0	-	12	$ 576,471	$ 67,349
GEHP	$/Th Saved	18.12								
Solar 100%	$/th saved	25.72								

Source: Occidental Analytical Group

The results show that installation of a GEHP with a target COP of 2.0 has the lowest NPV. The analysis also indicates that the addition of solar thermal heating does not improve the cost effectiveness. The annualized cost of the higher COP GEHP is the lowest and if the replacement of the existing storage tank is taken into consideration, the lower COP GEHP could have a better NPV than the existing equipment replacement option. Simple pay back of the high efficiency GEHP option is attractive at six years. The table also calculates the cost of savings on a per therm basis, which indicates that solar thermal heating costs/therm is much higher than the GEHP cost/therm.

Table 5 provides a benefit/cost ratio based on incremental cost versus incremental benefits. Again, if the GEHP delivers the rated efficiency (COP) of 2.0, the benefit/cost ratio is the highest.

Table 5: Calculation of Benefit/Cost Ratio

Calculation of Benefit/Cost Ratio						
Option	Installed	Incremental	Present Value (PV) of Incremental	Present Value (PV) of Operating	Present Value (PV) of Benefits	Benefit/Cost Ratio
	Cost $	Cost $	Cost $	Cost $	(Savings $)	B/C
Baseline Operation(replacement)	$ 101,500	$ -	N/A	$ 242,445	N/A	
GEHP COP 1.05	$ 186,000	$ 84,500	$ 84,500	$ 228,200	$ 14,245	$ 0.17
GEHP COP 2.0	$ 186,000	$ 84,500	$ 84,500	$ 152,331	$ 90,114	$ 1.07
GEHP COP 1.05 +Solar TH (20 Panels)	$ 271,000	$ 169,500	$ 169,500	$ 237,906	$ 4,539	$ 0.03
GEHP COP 2.0 +Solar TH (20 Panels)	$ 271,000	$ 169,500	$ 169,500	$ 169,624	$ 72,821	$ 0.43
Install 100% Solar Thermal	$ 422,400	$ 320,900	$ 320,900	$ 154,071	$ 88,374	$ 0.28

Source: Occidental Analytical Group

Table 6 provides the GHG emissions and reduction for each alternative. Other than 100 percent solar thermal, the lowest GHG emissions is by the GEHP delivering at least a COP of 2.0.

Table 6: GHG Emissions & Reduction

GHG Emissions & Reduction			
Option	GHG Emissions Tons/Yr	GHG Reduction Tons/Yr	GHG Reduction Percent %
Baseline Operation(replacement)	96.06	N/A	0%
GEHP COP 1.05	68.61	27.44	29%
GEHP COP 2.0	36.02	60.04	63%
GEHP COP 1.05 +Solar TH (20 Panels)	61.75	34.31	36%
GEHP COP 2.0 +Solar TH (20 Panels)	32.42	63.64	66%
Install 100% Solar Thermal	0.00	96.06	100%

Source: Occidental Analytical Group

CHAPTER 10: Technology Transfer

Through this demonstration, the project team sought to obtain real-world data on the technical and economic feasibility, reliability, and durability of the integrated system. The results of the demonstration could help overcome the primary barriers to wide-scale deployment. The results of this project illustrate the inherent risks, both financial as well as technological for customers, system designers and utility companies. The supporting economic analysis could provide natural gas utilities the basis for design and implementation of energy efficiency programs and support development of energy codes and standards.

The ETC scalability allows the GEHP to be installed in facilities that use substantial amounts of hot water such as in hotels, commercial laundries, food processing, prisons, large restaurants, and hospitals. The only challenge is the physical space required for the applications. Solar thermal collectors compete for roof space with solar photovoltaic collectors and the GEHP and associated storage tank require additional space near the existing DHW system.

The demonstrated GEHP and ETC solar thermal technology are under-utilized, and an optimal integration of these technologies could maximize energy efficiency and decrease GHG emissions for multiple markets. Known market barriers for these systems include, but are not limited to: lack of consumer and installer awareness and demand; lack of high-quality field performance data; small trained installer base; under-developed supply chain; higher up-front material costs, increased design and/or labor costs; challenges in optimizing the sizes for both technologies to maximize energy savings at the lowest cost, energy savings calculations, controls strategies, and installation/commissioning; and uncertainties with regard to system performance.

There should be an effort made to incentivize this integrated solution in large multifamily customer sites and other markets. In addition, if the industry is to be sustained, workforce training and development for multifamily, commercial, and industrial application of this integrated system application should be expanded in the state's trade schools and community colleges.

To disseminate the lessons learned from this project, interdisciplinary collaboration is essential. Knowledge gathered through this project will be communicated to multiple audiences to accelerate the deployment of the technologies in diverse markets. Stakeholders in an outreach effort can include scientific community and academia, state and local building departments, natural gas utility companies, air quality boards, and codes and standards communities such as the CEC, system designers, implementers, and facilities and building operators, owners management companies.

The project team developed outreach and communication materials such as a fact sheet to be distributed to potential customers, industry groups and in technical conferences. Throughout the course of the project, Energx held meetings with the Technical Advisory Committee members and the CEC to discuss the scope of the project and request recommendations for technology transfer/information dissemination. The project team met with Southern California Gas Company to create awareness about the integration of a GEHP with solar thermal to meet state energy and GHG emission goals.

The project team was a presenter in the California Emerging Technologies Coordinating Council's event on Natural Gas Water Heating in a zoom conference in which more than 30 individuals from the California utilities, industry experts, and trade associations attended. The project team actively participated in various networks with other organizations, such as equipment suppliers, competitors, contractors, sub-contractors, utilities, governments, and professional associations. Upon completion of the Final Report, and with the approval from the CEC, the Final Report will be uploaded to Energx's website for public dissemination. It will be shared with the key stakeholders.

CHAPTER 11: Benefits to State of California

The GEHP and ETC solar thermal technology are emerging and/or underused resources, and their optimized integration has not been extensively applied in many market sectors within the United States. Although the GEHP has been introduced in the market, especially in multifamily projects on the east coast, there is a dearth in the real world of demonstrated and documented benefits of the technology integrated with solar thermal application. Customer interest can only be generated through this type of on-site technology demonstration followed by dissemination of lessons learned and economic benefits.

The advancement of knowledge about these technologies will be valuable to property owners in their quest to implement sustainability plans, state policy makers in furthering policy, codes, and standards, and utilities to offer incentives in their energy efficiency programs.

If the integrated technology were to be implemented on a statewide basis, using the CEC's Energy Efficiency Data and conservative assumptions, calculations were made on annual energy savings, GHG, and NOx reductions. Table 7 below assumes that:

- Fifty percent of multifamily DHW loads are in large apartment buildings.
- They are able to benefit from the technologies that were demonstrated.
- The technologies are implemented over a period of 10 years.

Table 7: Annual Energy & Emissions Calculations

Multifamily Section – State of California

Total Multifamily DHW energy use	264.48	Mil Th
Assume 50% in larger MF Bldgs	132.24	
Assume Combined GEHP+Solar savings	75	percent
Energy saved	99.18	Mil Th
GHG Emission of Nat Gas	11.7	lb/th
One ton	2000	
Annual Tons of GHG Reduction	580,203	tons
Assume existing WH rated NOx emission	9	ppm
GEHP emission assume	9	ppm
Equivalent NOx emission lbs @ 9ppm	0.011	per mil Btu
Annual NOx reduction	55	tons

Assumptions:

Multifamily DHW therm consumption from GFO 16-502 Attachment 13
Assume latest SCAQMD Standard for Rule 1146 for large Water Heaters

Source: Energx

Then, statewide annual savings could be 99 million therms, which translates to 580,203 tons of GHG reduction, and 55 tons of NOx reduction. Cost savings based on a commercial gas rate of $1.50/therm the annual savings to California customers will be $148.50 million dollars.

Intangible benefits are often estimated by the California Air Resources Board and the SCAQMD in their air quality regulations and rulings. Some of the intangible benefits due to reduced fuel use would be the increase in capital expenditure by building owners resulting in job creation and growth. Other benefits due to emissions reduction could be life extension, better health, reduced healthcare costs due to reduced allergies and respiratory diseases.

For the participating customer and other multifamily building owners, the use of these technologies will result in a reduction of energy use, increased DHW system efficiency, and operational cost-effectiveness of the DHW system. Other benefits include system reliability, sustainability, GHG reduction, and competitive advantage.

Large scale adoption of the technologies through utility energy efficiency programs or state Codes and Standards regulation could result in lower dependence on fossil gas, lower avoided costs, quality job creation, improved health, economic development, reduction in GHG emissions, and improved quality of life in the state of California.

The recent rises in fossil gas prices will have a profound impact on California customers and ratepayers that have high gas use. With the newly adopted zero carbon initiatives and a goal of future electrification, fossil gas prices are going to rise significantly. The demonstrated technologies can significantly displace fossil gas consumption in the state and reduce operating costs and emissions reduction.

CHAPTER 12: Conclusions

The project at Park West Apartments was a research and demonstration project using two emerging and underused technologies, the gas-engine heat pump and the evacuated tube collector. There was a lot of time involved in the planning, design, understanding the nuances of the two technologies, and their start-up and operation. Construction also involved some delays in delivery of the GEHP, solar collectors, heat exchangers, and the pumps, which together with the onset of the COVID-19 pandemic, significantly delayed the project schedule.

The M&V of the project, as reported in Chapter 6, shows that the GEHP did not perform well. The calculated COP is around 1.05 while the expected COP was greater than 1.6, or 2.0. Due to the low GEHP COP, the solar thermal system hot water production was as high as 50 to 60 percent, which was an anomaly. The expected portion of heat delivery with the 20 panels was 10 percent.

The project team worked with Tecogen to investigate the reasons for the low COP. Investigation of ,and subsequent correction of the air flow over the evaporator to the rated level of 21,000 cfm, only slightly improved the COP. Tecogen believes there could be engine-compressor compatibility, or the refrigeration cycle operation could be an issue.

The project team did an economic analysis of the technologies and their application in the project. The economics assumed two different COPs of the GEHP, because the performance issue was not resolved. The analysis indicates that if the rated COP were achieved, the NPV of the costs is lower than replacement cost of the existing technologies, and the simple payback can be as low as six years. The analysis used a real-world installation cost, as in the marketplace, demonstrating that the labor rates do not have to be in prevailing wages.

Due to the prolonged delays and the troubleshooting of the GEHP, the budget became an issue as funds ran out and the team was thankful that Southern California Gas Company stepped up with some funding. Nevertheless, the project team worked hard to complete the installation and monitor the performance. Overall, it was a challenging experience for everyone involved.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
A	ampere or amp
AC	alternating current
ASHRAE	Formerly known as the American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	British thermal unit
°C	degrees Celsius
CCF	centum cubic feet (i.e., 100 cubic feet)
CEC	California Energy Commission
cfm	cubic feet per minute
COP	coefficient of performance
CO_2	carbon dioxide
CO_2e	CO_2-equivalent
DHW	domestic hot water
ETC	evacuated tube collector
°F	degrees Fahrenheit
ft/s	feet per second
ft^3	cubic feet
GEHP	gas-engine heat pump
GHG	greenhouse gas
gpm	gallons per minute
Hz	hertz
kBtu	thousand British thermal units
kVA	kilovolt-ampere
kVAR	kilovolt-ampere reactive
kW	kilowatt
lbs.	pounds
M&V	measurement and verification
m/sec	meters per second
m^3/h	cubic meters per hour
mA	milliampere
min.	minute

Term	Definition
mm	millimeter
mph	miles per hour
µA	microampere
mV	millivolt
nA	nanoampere
NOAA	National Oceanic and Atmospheric Administration
NOx	nitrous oxide
NPV	net present value
ppm	parts per million
psia	pounds per square inch absolute
psig	pounds per square inch gauge
SCAQMD	South Coast Air Quality Management District
SCFH	standard cubic feet per hour
SRCC	Solar Rating and Certification Corporation
Ta	ambient air temperature
Ti	inlet fluid temperature
Trms	true root mean square
V	volt
VA	volt-ampere
VAR	volt-ampere reactive
VDC	volt direct current
Vrms	root mean square voltage
W	watt
w.c.	water column

References

SoCalGas (Southern California Gas Company). 2010. "Rule No. 02 Description of Service." Southern California Gas Company. California Public Utilities Commission Sheet Number 45832-G. Available at https://www.socalgas.com/regulatory/tariffs/tm2/pdf/02.pdf.

SoCalGas. 2018. "Monthly Billing Factor." Southern California Gas Company. Available at https://www.socalgas.com/pay-bill/understanding-your-bill/btu.

U.S. EIA (United States Energy Information Administration). 2018. "Frequently Asked Questions (FAQs): What are Ccf, Mcf, Btu, and therms? How do I convert natural gas prices in dollars per Ccf or Mcf to dollars per Btu or therm?" United States Energy Information Administration. Available at https://www.eia.gov/tools/faqs/faq.php?id=45&t=8.