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THE EARTH-COUPLED HEAT PUMP:

Utilizing Innovative Technology in Single Family Rehabilitation Strategies

Urban Consortium

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Urban Consortium
Energy Task Force

CITY OF HOUSTON

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THE ENERGY TASK FORCE OF THE URBAN CONSORTIUM FOR TECHNOLOGY INITIATIVES

The Urban Consortium for Technology Initiatives (UC) is composed of over forty of the largest cities and urban counties by population in the United States. The Consortium provides a unique forum to define urban problems common to its member governments and to develop, apply, transfer and commercialize technologies and innovative management techniques to address those problems.

With staff, management and business services provided by Public Technology, Inc., the Urban Consortium carries out its work through special projects and Task Forces that focus on specific functional areas of local government management. The UC Energy Task Force is the nation's most extensive cooperative local government program to improve energy management and technology applications in cities and urban counties. Its membership is composed of local government officials from twenty of America's largest urban centers.

The members of the UC Energy Task Force define annual work programs to meet three specific objectives:

- definition of critical urban energy problems;
- development of technologies and management practices to resolve these problems; and
- transfer of resulting solutions to Urban Consortium and other local governments.

Proposals to meet the specific objectives of these annual work programs are solicited from the full UC membership. Projects based on these proposals are then selected by the Energy Task Force for direct conduct and management by staff of city and county governments. Projects selected for each year's program are organised in thematic units to assure effective management and ongoing peer-to-peer experience exchange, with results documented at the end of each program year.

This approach for the definition of priorities and the selection, conduct and documentation of applied research projects by staff from participating local governments is a unique strength of the UC Energy Task Force -- a "user-driven" focus to assure that projects conducted by city and county staff will produce results that effectively meet energy management needs critical to local governments.

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Costis Toregas, President

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Energy Task Force
of the Urban Consortium
for Technology Initiatives

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CITY OF HOUSTON

PREFACE

The Urban Consortium for Technology Initiatives was formed to pursue technological solutions to pressing urban problems. the Urban Consortium conducts its work program under the guidance of Task Forces structured according to the functions and concerns of local governments. The Energy Task Force, with a membership of municipal managers and technical professionals from twenty-one Consortium jurisdictions has sponsored over 180 energy management and technology projects in forty-six Consortium member jurisdictions since 1978.

To develop in-house energy expertise, individual projects sponsored by the Task Force are managed and conducted by staff of participating city and county governments. Projects with similar subjects are organized into *Units* of four to five projects each, with each Unit managed by a selected Task Force member. A description of the Units and projects included in the Ninth Year (1986-89) Energy Task Force program follows:

UNIT -- LOCAL GOVERNMENT OPERATIONS

Energy used for public facilities and services by the nation's local governments totals about 1.5 quadrillion BTU's per year. By focusing on applied research to improve energy use in municipal operations, the Energy Task Force helps reduce operating costs without increasing tax burdens on residents and commercial establishments. This Ninth Year Unit consisted of six projects:

- **Kansas City, Missouri** -- *Direct Digital Control of an Air Washer System*
- **Memphis, Tennessee** -- *The Use of Transportation Management Associations to Achieve Energy Conservation Benefits in Urban Areas*
- **Montgomery County, Maryland** -- *Requirements for Energy Efficient Building Construction*
- **Phoenix, Arizona** -- *Energy Cost Reduction in Comfort Cooling Through Cogeneration*
- **Phoenix, Arizona** -- *HVAC Equipment Replacement for Best Size and Efficiency (Technology Transfer)*
- **San Jose, California** -- *Energy Master Planning for Local Government Facilities*

UNIT -- COMMUNITY AND ECONOMIC DEVELOPMENT

Of the nation's estimate population of nearly 240 million, approximately 60 percent reside or work in urban areas. The 543 cities an counties that contain populations greater than 100,000 consume 50 quadrillion BTU's annually. Applied research by the Energy Task Force helps improve the economic vitality of this urban community by aiding energy efficiency an reducing energy costs for the community as a whole. This Year Nine unit consisted of six projects:

- **Chicago, Illinois** -- *Chicago Energy Demonstration Zone*
- **Houston, Texas** -- *The Feasibility of Incorporating Alternative/Innovative Technologies in Mass Single Family Housing Rehabilitation Strategies*
- **New Orleans, Louisiana** -- *Small Business Assistance Program to Reduce Energy Consumption Through Innovative Financing Methods (Technology Transfer)*

- o **New Orleans, Louisiana** -- *Development of an Energy Information an Referral Service*

- o **New York, New York** -- *Marketing Energy Efficiency Programs to Commercial an Industrial Firms*

- o **San Francisco, California** -- *Energy Planning for Economic Development*

UNIT -- ENERGY AND WASTE MANAGEMENT

Effective use of advanced energy technology an integrated energy systems in urban areas could save from 4 to 8 quadrillion BTU's during the next two decades. Urban governments can aid the capture of these savings an improve capabilities for the use of alternative energy resources by serving as test beds for the application of new technology. This Year Nine unit consisted of four projects:

- o **Albuquerque, New Mexico** -- *Hazardous Waste as an Energy Manager's Issue*

- o **Baltimore, Maryland** -- *Ammonia Oxidation by Separable Micro-supported Biomass for Nitrification of Sewage*

- o **Denver, Colorado** -- *Regional Workshops on Waste-to-Energy and the Management of Special Wastes*

- o **Detroit, Michigan** -- *Feasibility Assessment: Conversion of Resource Recovery Steam to Hot and Chilled Water Systems*

- o **Hennepin County, Minneapolis** -- *Special Household Waste Management*

- o **Seattle, Washington** -- *Implementation of Hazardous Waste Collection Option*

- o **Seattle, Washington** -- *Computerizing Municipal Procurement Choices (Technology Transfer)*

Reports from each of these projects are specifically designed to aid the transfer of proven experience to staff of other local governments. Readers interested in obtaining any of these reports of further information about the Energy Task Force and the Urban Consortium should contact:

Applied Research Center
Public Technology, Inc.
1301 Pennsylvania Avenue, NW
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Acknowledgments

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CHAPTER 1 - OVERVIEW

ABSTRACT

The study examines the feasibility of incorporating the use of earth-coupled heat pump technology in single-family housing rehabilitation projects, based on energy conservation attributes and financial considerations. Following evaluation of a theoretical model which indicated that installations of the heat pumps were feasible, the heat pumps were tested under actual conditions in five single family housing units which were part of the Urban Homesteading Program, and were matched with comparable units which did not receive special treatment. Energy consumption information was collected for all units for twelve months. Variables were identified, and the data was analyzed for individual housing units and compared with the results predicted by the theoretical model to determine the practicality of incorporating such technology in large scale rehabilitation projects.

PROJECT PURPOSE

The purpose of the project is to validate the theoretical feasibility of incorporating ground source heat pump technology in single family rehabilitation strategies, and to establish the criteria under which such technology would provide optimal results in a large scale rehabilitation effort.

REPORT ORGANIZATION

Chapter 2 discusses the selection of a housing rehabilitation program suited to conducting a controlled experiment; the basis for the selection of the technology; the theoretical model which formed the basis of the experiment and the design of the project.

Chapter 3 describes the results of the tests and the issues which the project raised. Chapter 3 also summarizes the project staffs' conclusions based on the data gathered.

Chapter 4 discusses the financial considerations associated with large-scale application of the technology, including economies of scale and payback schedules.

Chapter 5 summarizes the lessons learned by the project staff during the study, and outlines the implications for additional study with a summary of the opportunities presented.

CHAPTER 2 - HOUSING REHABILITATION, THE TECHNOLOGY AND THE MODEL

INTRODUCTION

As utility costs have risen despite political campaign promises and conservation measures implemented by the utility companies, home owners have begun to search for effective methods of reducing their electricity bills. In some cases home owners are faced with utility bills that are approaching the cost of their mortgage payments. For those with fixed incomes, such as the elderly or those looking forward to retirement in the near future this has become an alarming reality. Virtually every home owner would like to reduce their utility bill: what items should be addressed in order to have a significant impact on his or her energy cost?

The answer depends on climatological factors, the source of heating and cooling power, and personal choices and preferences. In the subtropical climate of the Texas Gulf Coast, known for its long summers, mild winters and consistently high levels of ambient humidity, 50% of an electricity bill can be attributed to the air conditioning system, according to Houston Lighting & Power Company, and another 15% - 20% to the hot water heating system.[1] Therefore, to effect a dramatic reduction in residential utility costs, one should look first at these two "energy gulpers" and next at proper home weatherization, including insulation, window coverings, etc.[2]

To evaluate these systems within the context of existing single family residential construction, several factors must be considered. As a part of low cost rehabilitation and retrofit, limitations exist in the selection of an energy source and optional design features such as orientation and fenestration which significantly impact energy consumption.

The amount and type of vegetative screening is also a factor to be considered. The 579 square miles located within the corporate limits of the City of Houston is at the apex of three geographic areas which support quite divergent plant forms: the northeast area from the southernmost boundary of the pine forests of east Texas, with a sandy alkaline soil; to the south and southwest, alluvial deposits of the great river systems have formed a cohesive clay basis dusted with topsoil which supports deciduous trees amid the grasslands; and to the west and northwest the prairie converges with that of the Texas Hill Country, where native and live oaks are the predominant trees.

New home buyers have many options to choose from. Often the type of style of the whirlpool bath receives more attention than the energy-consuming devices in the home. Since the air conditioner and water heater consume approximately two-thirds of the electricity used in a typical month, the energy efficiency of these two appliances should be an important factor in the purchase decision. Over the last 40 years central air-conditioning has evolved from oscillating fans, to window units, to split-system air conditioning systems with either gas or electric furnaces.[3] Up until recently there was little consideration given by either manufacturers, contractors or home buyers to the efficiency of the heating and cooling system.

However, the Arab oil embargo changed that situation dramatically as utility bills began to skyrocket electric rates continued a steady rise, as illustrated in the last eleven years in Houston where the average annual rate of increase from Houston Lighting and Power was seventeen percent. Now high efficiency air conditioning systems are being actively promoted by the utilities and the air conditioning contractor alike.

Similarly, during the past few years heat pumps have gained in popularity in new construction due to heavy promotion from electric utility companies. In the case of the latter, the utility company's interest is prompted by the desire to use excess capacity in the winter months, while reducing the bills of customers who use electric resistant heat as their primary heating source.[4] The more limited use of heat pumps in rehabilitation projects can probably be traced as much to public inertia as to any other cause, particularly among segments of the lower socio-economic population, where limited resources and limited education combined with the urgencies of daily subsistence, have relegated energy conservation issues to a lesser status. Where the rehabilitator is not the home owner but a public or private agency, the perception that the technology is experimental, coupled with the high capital cost of the individual pump installation has retarded the use of heat pump technology in public housing rehabilitation projects.

The choices and preferences of the individual resident also play a distinct role in defining the total energy consumption picture: factors such as thermostat settings, the presence of one or more persons at home during peak daytime cooling periods, the presence of persons other than the rate payer who are less sensitive to the need to reduce energy consumption as a means to reduce costs, may be significant if not decisive in securing the desired savings, as our study clearly reveals.

In order to test the hypothesis that innovative energy conservation technologies could be introduced with positive effect into mass single family housing rehabilitation strategies, it became essential to control the variables to establish reliability of test results. Once the controls were established, it was necessary both to establish a system for measuring the results of the units tested with similar conventional units, and to adopt a methodology for comparing those results with a theoretically derived result under optimal conditions. Extrapolating from the results of the test, it was then possible to establish the point at which the energy conservation benefits of the technology would equal or exceed the costs, assuming certain economies associated with a large scale implementation effort.

Key elements in establishing the framework of the study were: determining the housing rehabilitation project or program which would best support the objectives of the study; determining the technology which had both the most potential for energy conservation and which would be most suitable for implementation in a large scale housing rehabilitation environment, and lastly, ensuring that the tests were designed and conducted in a manner which could be scientifically replicated, acknowledging that the number of test units in this original study was very small.

HOUSING REHABILITATION

The project staff analyzed various housing rehabilitation efforts conducted in the City of Houston at the time the study was initiated. Conventional rehabilitation undertaken by the Housing Authority of the City of Houston in their scattered site housing program had great appeal: it was a successful program designed to assist families from the very lowest income bracket, clearly those with the most to gain from reduced electric bills. On the other hand, the project staff, which included representatives from several departments, would have very limited control over the installation or location of the units, and a very limited opportunity to follow up with project participants. The staff was also concerned that since the project involved the installation of fixtures which required routine maintenance by the resident, that tenant residents would be less amenable to active participation than those with a permanent stake in the success of the project.

Private sector initiatives for home ownership funded through the City's Community Development Block Grant program were in developmental stages: the units undergoing rehabilitation through the program had the advantage of being in close geographic proximity to one another and were programs designed to assist the very low income family, but within the context of home ownership these factors were clear advantages from the project perspective. The number of units which were to be included, would be insufficient to provide an adequate number of similar conventional and untested units for project purposes. Additionally, although all units were certain to be rehabilitated to conform to minimum building code requirements, the work was to be undertaken by private contractors independent of City supervision. Thus, there were no assurances that all units would be treated in a uniform manner, particularly since a number of the units had been converted to commercial uses in the past.

Surprisingly, the City's own single family rehabilitation program, the Houston Housing Improvement Program (HHIP) shared many of the same difficulties as programs managed by the Housing Authority and the private sector: participation in the program was on a first-come, first-served basis according to need, with project locations dispersed throughout various areas of the inner City. Rehabilitation work beyond minimum code requirements was not uniform, dependent to a large extent on the wishes and means of the home owner, who often remained in residence during construction. Participants in the HHIP program were already home owners, and though the program did not limit participation to the lowest end of the income scale, home owners were often elderly widows and widowers, and therefore not representative of the cross-section of the City, where the average age of residents was between 27 and 34 years of age. Age, as we later observed, played a significant role in determining personal allocation of resources and in establishing "comfort" in ambient temperatures.

The Urban Homesteading Program appeared ideally suited to the project. The program was under the direct control and supervision of the City, and was designed to take advantage of vacant and foreclosed housing which is made available to qualified low and moderate income persons. In order to qualify, the individual may not have owned a home, must have good credit and the ability to undertake the repairs on the property, either through their own labor, (so called "sweat equity"), or through a rehabilitation loan arranged through the City, or some combination of the two. The houses are deeded over to the participant after a period of five years, provided that the rehabilitation loans are serviced on a timely basis and that the resident actually lives in the house. While families always retain the power to reject a house, the size of the family is an important criterion in determining the size of the house for which the family is eligible, and ultimately for limiting the pool of participants for individual houses. For the purposes of our energy project, this policy had the effect of making the human variable more uniform on a unit basis, at least in terms of the numbers of persons residing in the unit. The Urban Homesteading Program had an additional plus from the project perspective: the lotteries for the homes are undertaken periodically, and the homes included in individual lotteries are ordinarily purchased from the department of Housing & Urban Development (HUD) or the Veterans Administration (VA) in groups of five or more. Often these groups are located close together or even within a single neighborhood, and often were originally constructed at about the same time, thereby establishing uniform environmental conditions for evaluating energy consumption criteria.

The end product of the rehabilitation effort is relatively uniform among all units, and no unit is occupied until rehabilitation work is complete. The size of the group usually varies between sixteen and about twenty units, providing a sufficient number of uniform units to adequately test the hypothesis advanced. The Urban Homesteading Program is one that is extremely popular with residents, participants and elected officials, since participants have achieved the "American Dream" of home ownership, and since the effect of the program in reclaiming deteriorating or abandoned residential neighborhoods has been dramatic.

Following this initial analysis, the decision was made to include all of the units in the Urban Homesteading Program. All units were located in the northeastern part of the City, which was designated as the Settegast Urban Homestead Area.

Clearly, while the new home owners often experience the tribulations of ownership, mitigated to some extent by counseling offered through the City, their attitude was generally positive and enthusiastic. This attitude of cooperation and the willingness to adapt to new ideas by program participants is recognized as one of the most important albeit unforeseen requirements of the success of this project.

THE TECHNOLOGY

A heat pump operates like a standard electrically driven air conditioner in the summer, collecting heat from the air in the outdoor air to warm the air inside the house.[5] The heat pump can do this because heat exists in air. Even cold winter air contains heat. On very cold days most heat pumps will have to rely on supplemental resistance heaters to provide sufficient heating for the space.

The efficiency of the heat pump is very good relative to a fossil fuel-burning furnace or resistance heat since the heat pump collects heat that already exists in the outdoor air by means of its refrigeration cycle. This means that the heat pump supplies from 1 1/2 to 2 1/2 times more energy in the form of heat generated than it consumes in energy as electricity, depending on the efficiency of the unit and the geographic location.

The problem with air to air heat pumps, which is the type with which most people are familiar, is that they depend on the outside air temperature to move the heat into or out of the house. This means that the colder it gets outside, the less efficient the heat pump becomes. Also, as temperatures rise in the summer the heat pump becomes less efficient in removing heat from indoor air and rejecting it to outdoor air.[6]

THE EARTH-COUPLED OR GEOTHERMAL HEAT PUMP

What if there were a source of heat that was at a relative constant temperature of 55°F - 75°F? Then the system could operate in a very efficient range. Systems that have been developed to utilize these constant temperatures are called "earth-coupled" or "geothermal heat pumps". These systems still use the basic heat pump design, moving heat from one source to another, but also take advantage of the relatively constant earth temperature. Generally at depths of about 30 to 50 feet the earth remains at a constant temperature, reflecting the average air temperature of the area.[7] In south Texas this will vary between 69°F - 74°F, which is ideal for efficient operation.[8]

These geothermal heap pump systems were first developed 25 years ago by Swedish engineers in response to Sweden's increasing dependence upon foreign imports of oil and coal. The earth-coupled heat pump was designed, tested and now, after hundreds of thousands of installations, has become the standard installation of this country. Shortly after the Swedes developed this technology, Canada followed suit for similar reasons.

About 12 years ago Dr. Jim Bose, of Oklahoma State University, became interested in the earth-coupled heat pump. He requested and received a federal grant to research the applicability of this design in the U.S.. Since then, both Bose and Dr. Harry Braud of Louisiana State University, have developed sufficient research, testing, and mathematical models to predict the length of pipe for proper coupling with a geothermal heat pump. A study underway at Texas A & M University, under the direction of Professor Bill Aldred of the Agriculture Engineering Department will develop a mathematical model of the heat transfer characteristics in an earth-coupled system. Professor Aldred will be utilizing a three ton geothermal heat pump connected to a vertical parallel loop system. The system's heat transfer will be monitored by 99 thermistors installed at various locations throughout the earth loop.[9]

There are two basic types of earth-coupled systems currently used in the U.S.: open loop and closed loop (either horizontal or vertical).

OPEN LOOP SYSTEM

The distinguishing feature of an open loop system is the use of groundwater as a heat source/sink (see Figure 1). Water is pumped from a well, flows through a heat exchanger, and then is discharged back to the environment.

A variety of discharge systems may be used to dispose of the water. A recharge well can be constructed, allowing the water to reenter the ground-water for use later. Recharge wells will have different characteristics depending on the geological conditions and water quality. In many places unlimited quantities of water can be injected into formations, but in areas where the static water level is high it may be necessary to discharge the water at a different depth. The supply well should be a minimum of 50 feet from the discharge well to prevent heat from building up in the system.[10] Shallow tile fields, septic type systems or drains all allow the water to be returned to the ground, thus replenishing the groundwater supply. Water may also be discharged into lakes, streams or rivers and even storm sewers. All of these methods are subject to local and state approval so that the groundwater is not polluted, although ordinarily the only change is a slight increase in groundwater temperature.[11]

The typical open system uses 2 1/2 to 3 gallons per minute (gpm) per ton of cooling capacity and produces a temperature change of 10^{o}F to 12^{o}F in the groundwater. If an adequate well is already available on the property, only slight modifications to the water system and a method of disposing of the water are needed. If the

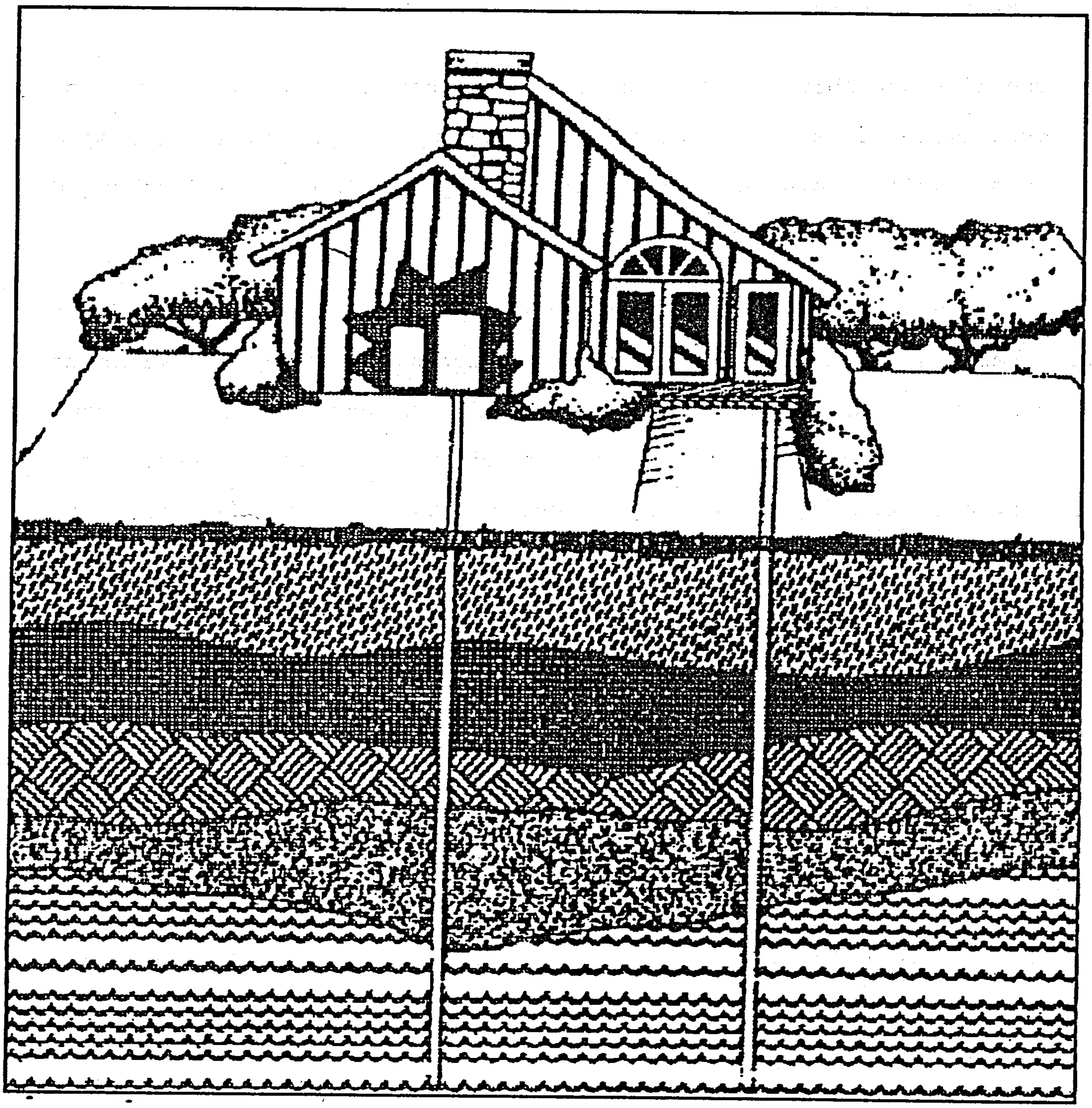


Figure 1

house derives its water supply from another source, however, such as a water supply utility, a well must be drilled and a complete water supply and disposal system installed. Costs for the open system may vary depending upon whether a water system is already available, and the type of disposal method chosen.[12]

The main drawback to open loop systems is the quality and quantity of water required for operation. In rural areas, a well capable of producing 20 to 30 gpm is needed to meet the heat pump needs and peak domestic water needs of the household. Farm households need even more water.[13] In urbanized areas of any size, including Houston, water is a scarce and precious resource, a condition which eliminated the use of the open loop system very early in the analysis.

Even where water quality is found in sufficient quantity, the mineral content (calcium and iron are good examples) may tend to foul the system by depositing a scale or sludge on the heat exchanger. Wells, pumps, and water systems require additional maintenance as a result, thereby increasing the cost of operating the system.[14] A significant portion of this maintenance of the unit's heat exchanger may, however, be eliminated by the development of a new cuprous-nickel alloy that inhibits the development of scale.[15] The cuprous-nickel alloy expands and/or contracts very rapidly as it is heated or cooled. The expansion or contraction tends to break off mineral deposits which are then flushed out of the system. This alloy is very resistant to corrosion, even by salt water.[16]

CLOSED LOOP SYSTEM

A closed loop system obviates many of the problems associated with the open loop system by circulating a liquid through a length of buried pipe to capture the heat in the soil, and returning the warmed liquid to the heat exchanger to be cooled and recirculated over and over again. No groundwater is used. Nothing is pumped out of or recharged back into the ground since the system is fully sealed This system has been available in the U.S. since the 1970's, and may be of two types: horizontal and vertical.

Horizontal systems (see Figure 2.) are installed in a wide range of patterns and methods, the simplest design being the single pipe loop. A pipe (usually 1 1/4 inch polybutylene or polyethylene plastic) is installed in a trench three to four feet below ground. The length and pattern of the pipe layout varies depending upon soil conditions, local climate, heat pump design, and available land area. Eleven hundred or two thousand feet of trench and pipe for a single pipe system is typical for a three-ton system. By installing two or more pipes in the same trench total trench length can be shortened.[17]

The vertical closed loop (see Figure 3) is somewhat simpler to design and can be used in areas where closely spaced homes are built. A vertical closed loop uses approximately 150 feet of borehole per ton. A three-ton unit, then, will use a total of 450 feet of borehole (or 900 feet of pipe) in a typical installation.[18]

A typical vertical loop system is installed in drilled boreholes and usually is separated into several loops (i.e.,

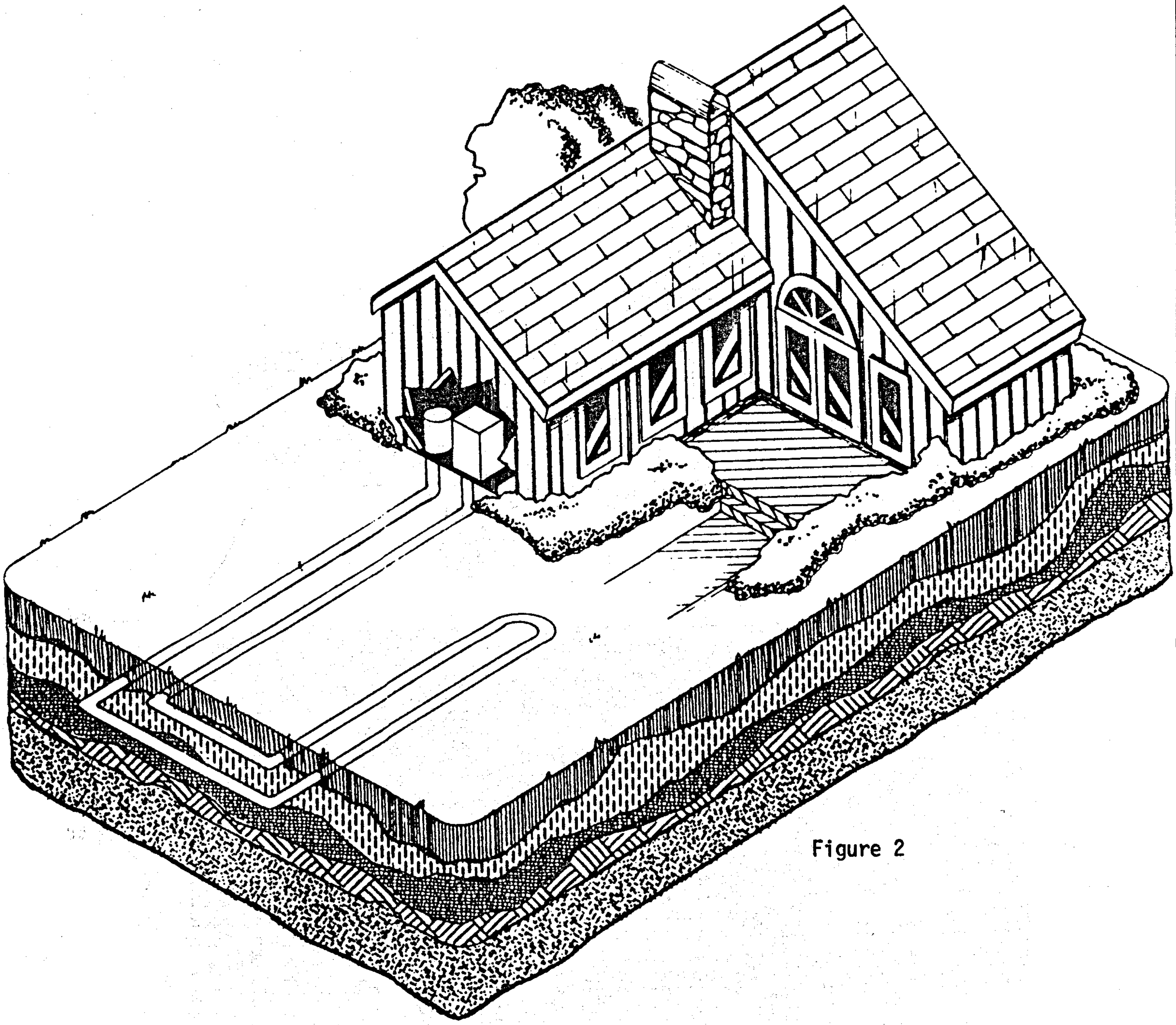


Figure 2

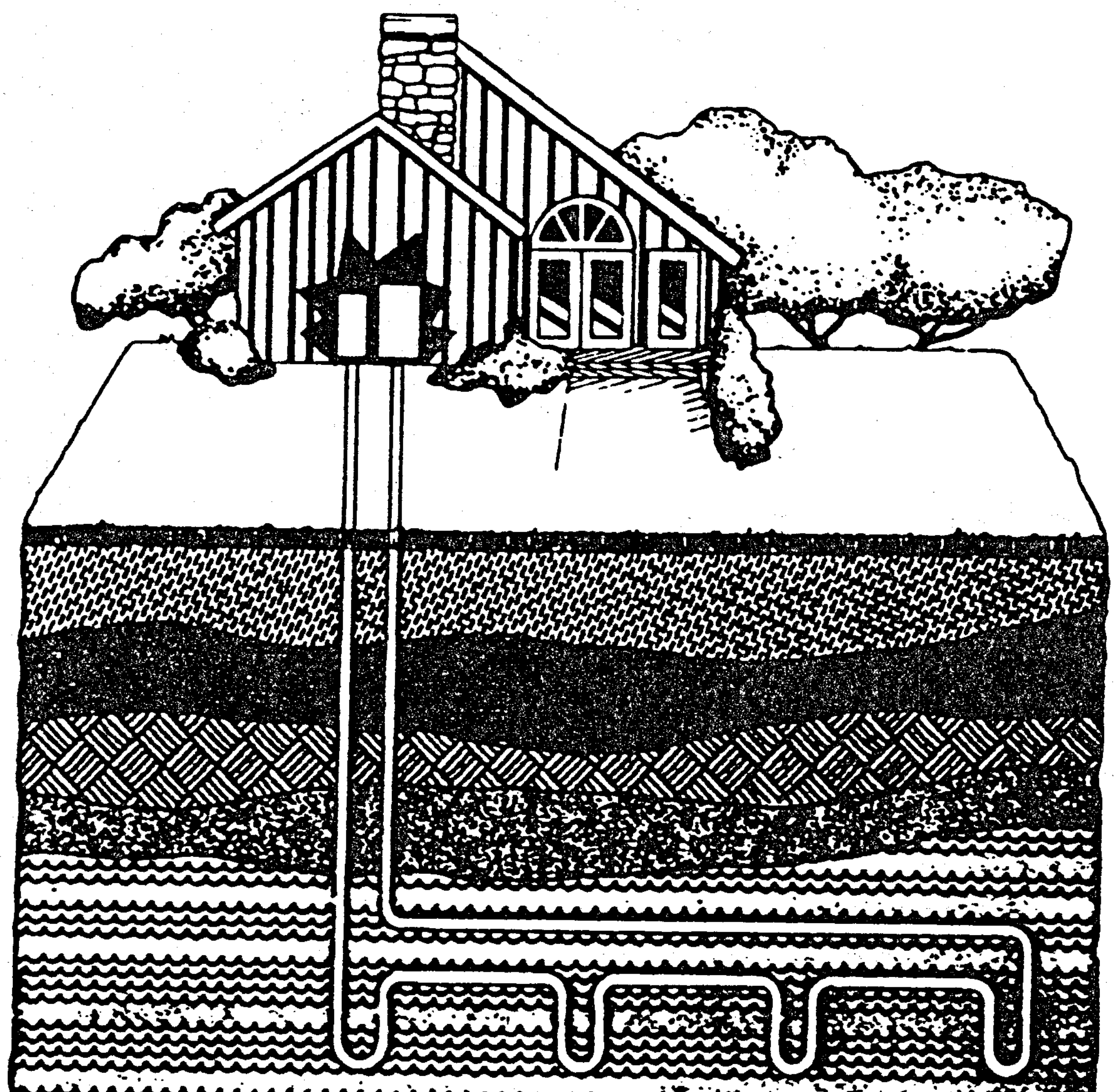


Figure 3

several 150 foot boreholes) using 3/4 inch polyethylene or polybutylene pipe with watertight butt-fused joints used through the system. This type of joining system ensures longevity and protection from leaks.[19]

The polyethylene or polybutylene pipe is best for this application due to its heat transfer rates and its resistance to environmental stress cracking. Further, all current research points toward the polyethylene or polybutylene pipe as being in the best long term interest of the consumer.[20] The pipe is designed to withstand pressures of 800 pounds per square inch (psi) and, in fact, operates at 20-30 psi.[21] The typical warranty of the pipe is 50 years. The two leading manufacturers of the pipe resin are Phillips Petroleum and Shell Chemical. Many other types of materials have been tested by Bose and Braud. All have been rejected as not being cost effective or as lacking reliability for this purpose. Currently, PVC (Polyvinylchloride) pipe is being used in some installations because of its low cost and the water well drillers' familiarity with this type of pipe, in spite of concerns within the industry relating to the pipe's ability to withstand the earth's environmental stress.

Once installed in the ground, the loops are pressure-tested, then filled with water or a solution of either calcium chloride or a food grade glycol. The latter two reduce the chance of ice crystals forming with the loop as the fluid passes through the heat exchanger.[22] In the south Texas area this is not necessary as the earth temperature never reaches $32^{o}F$ even very near the earth surface. However, if the home owner should vacate his house during a period of extended freezing weather, then either the system should be left operating at a lower temperature or drained just as any water system would be, to prevent rupture and subsequent water damage.[23]

SYSTEM EFFICIENCY

Why are closed loop systems so efficient? The temperature of water entering the heat exchanger remains nearly constant and, as a result, the heat pump can be designed for maximum efficiency. Because the water quality is controlled, no scaling or fouling which might reduce the efficiency of the system occurs within the heat exchanger.[24]

Currently about the most efficient conventional cooling unit has a seasonal energy efficiency ratio (S.E.E.R.) of 10, meaning that the unit is capable of producing 10 British Thermal Unit (BTUs) of Cooling effect for every watt of energy it consumes. However, the rating point for S.E.E.R. of air source units is an outside air temperature of 82^{o}F. This means that at temperatures exceeding 82^{o}F the air source system will experience a decrease in efficiency. Since the earth-coupled heat pump has an average energy efficiency ration (E.E.R.) of 13 it is at least 30% more efficient for cooling than the air source unit with an S.E.E.R. of 10. Earth-coupled heat pumps are not rated with an S.E.E.R. due to the fact that they use relatively constant temperatures, even when it becomes extremely hot outside.[25]

For the earth-coupled heat pump the heating efficiency is almost twice that of the next best device, the conventional air source heat pump. This standard heat pump will generally average a coefficient of performance (C.O.P.) of 2.1, whereas, for the earth-coupled heat pump it is approximately 4.0. This means the earth-coupled heat pump will produce 4 watts of energy for every watt of energy it consumes, whereas, the standard heat pump will produce only 2.1 watts. Furthermore, as the outdoor air gets colder the efficiency of the air source heat pump drops off significantly, while the earth-coupled heat pump continues to perform at peak efficiency since its heat source is well water or water circulated through the ground loop. Water has a specific heat much greater than that of many other substances and, therefore, can store or release far more heat for a given rise or fall in temperature.[26]

Evidence of the true cost effectiveness of these systems was recently demonstrated by tests conducted by the National Association of Home Builders Research Foundation and monitored for the Department of Housing and Urban Development on a test house built in Maryland with many energy saving devices installed. The Energy Efficient residence-2 (EER-2) provided answers that will help guide builders in the future as they consider what features to build into their homes. The EER-2 house was occupied in October, 1981, by a family of four and was closely monitored for a year to evaluate the effectiveness of the special energy conserving features. According to the test results the most cost effective features in the home was the earth-coupled heat pump. Savings in cooling and heating costs indicated less than a three year payback on the premium costs associated with the system, or in other words, a 33% return on investment.[27]

Similar proof of the economic advantages of the earth-coupled heat pump have been documented by operating results from a Massachusetts utility company. The Boston Edison Impact 2000 House is delivering three times more energy as heat than is consumed in electricity by its compressor and pumps. The earth-coupled heat pump system was selected for the air conditioning system for this utility company's show home to display the latest energy conserving features available in a home. Boston Edison has been conducting field tests for over three years on a number of homes in the area and has become convinced of the significant energy reductions available through the application of the earth-coupled heat pump.[28]

In the Gulf Coast area over 500 of these systems have been installed in the last two years. Results range from a home owner in a small home (2100 sq.ft.) who replaced her old gas furnace and split system air conditioner and is now saving more than 50% on her utility bills; to the retired engineer in Bellaire, Texas who put in a system 22 years ago and today reports monthly utility bills which are $100 lower than his neighbor's. The home owner in the first case, had a 3 1/2 ton vertical ground loop system installed, and the retired engineer had a shallow water well drilled to supply water for his system. The water is used to sprinkle his lawn after being circulated through his five ton geothermal heat pump.[29]

An optional feature of the earth-coupled heat pump is the desuperheater which extracts heat from the refrigerant to produce hot water. This option, which was not tested in this study, may reduce energy consumption for production of hot water by up to 80%.

EARTH COUPLED HEAT PUMP MODEL

The advantages and disadvantages of the earth coupled heat pump model are illustrated in the following chart. The theoretical model indicated that a residential unit of 1,600 square feet equipped with an earth coupled heat pump and occupied by a family of four would realize considerable annual energy savings. When compared with an air-to-air pump, approximately four million BTUs would be conserved annually, and between ten and twenty million BTUs would be saved when the earth pump is compared with more conventional units. This estimate is based on a S.E.E.R. of 9 for conventional electric or combination gas/electric systems, a S.E.E.R. of 10 for air-to-air heat pumps and a S.E.E.R. of 13 for the earth coupled system. This estimate assumes a constant temperature setting of 75^{o}F for cooling and 70^{o}F for heating under "average" ambient outdoor temperature conditions (See figure 4).

The opportunities for energy conservation were sufficient to indicate the feasibility of undertaking an empirical validation of these results. The theoretical model does not acknowledge extreme or rapid changes in outdoor temperatures, however, nor the particular problem of reducing variable humidity in a sub-tropical climate. Nevertheless, there was a strong indication that the amount of energy conserved would be sufficient to provide real dollar savings to the home owner, probably in an amount sufficient to offset the higher capital costs associated with the initial installation of the earth coupled heat pump system. This, in addition to the fact that the anticipated life of the mechanical unit is eighteen to twenty years, compared very favorably with the

THE EARTH COUPLED HEAT PUMP THEORETICAL MODEL

ADVANTAGES

1. Two-thirds of the energy used comes indirectly from the sun which is a renewable, non-polluting energy source.
2. An earth-coupled heat pump can be applied practically anywhere for residential, commercial and industrial heating/cooling systems.
3. There is no noisy, bulky outdoor condensing equipment required.
4. No back-up supplemental heating equipment is necessary.
5. An earth-coupled heat pump is a relatively simple machine requiring little if any maintenance.
6. An earth-coupled heat pump has the lowest operating cost of any space heating or cooling system.
7. F.H.A. will generally appraise a home with this system at a higher value.
8. No open flame is necessary, as is required on gas furnaces.[30]

DISADVANTAGES

1. Initial investment for a water supply or loop system. It should be noted that a packaged earth-coupled heat pump system and duct work (equipment installed indoors) costs approximately the same as other fossil fueled equipment with central air conditioning. Typically, a water supply system or loop will cost an additional $600.00 - $1,000.00 per ton of cooling capacity.[31]
2. Coordination of trades can be a problem during installation as two or more additional contractors are involved (well driller - trenching - plumbing). The ideal situation is to have someone stubbing the two loop or water supply lines into the house (outside turnkey operation).[32]
3. Many consumers are distrustful of heat pumps due to past bad experiences with air-to-air heat pumps. Geothermal units do not have a defrost cycle and the compressor sits inside, contributing to a much longer compressor life (19 years vs. 7 years, according to ASHRAE). Further, most consumers are not aware that geothermal units have been in use for over 25 years and are hesitant to experiment with "new technology".[33]

EARTH-COUPLED HEAT PUMP

The Theoretical Model

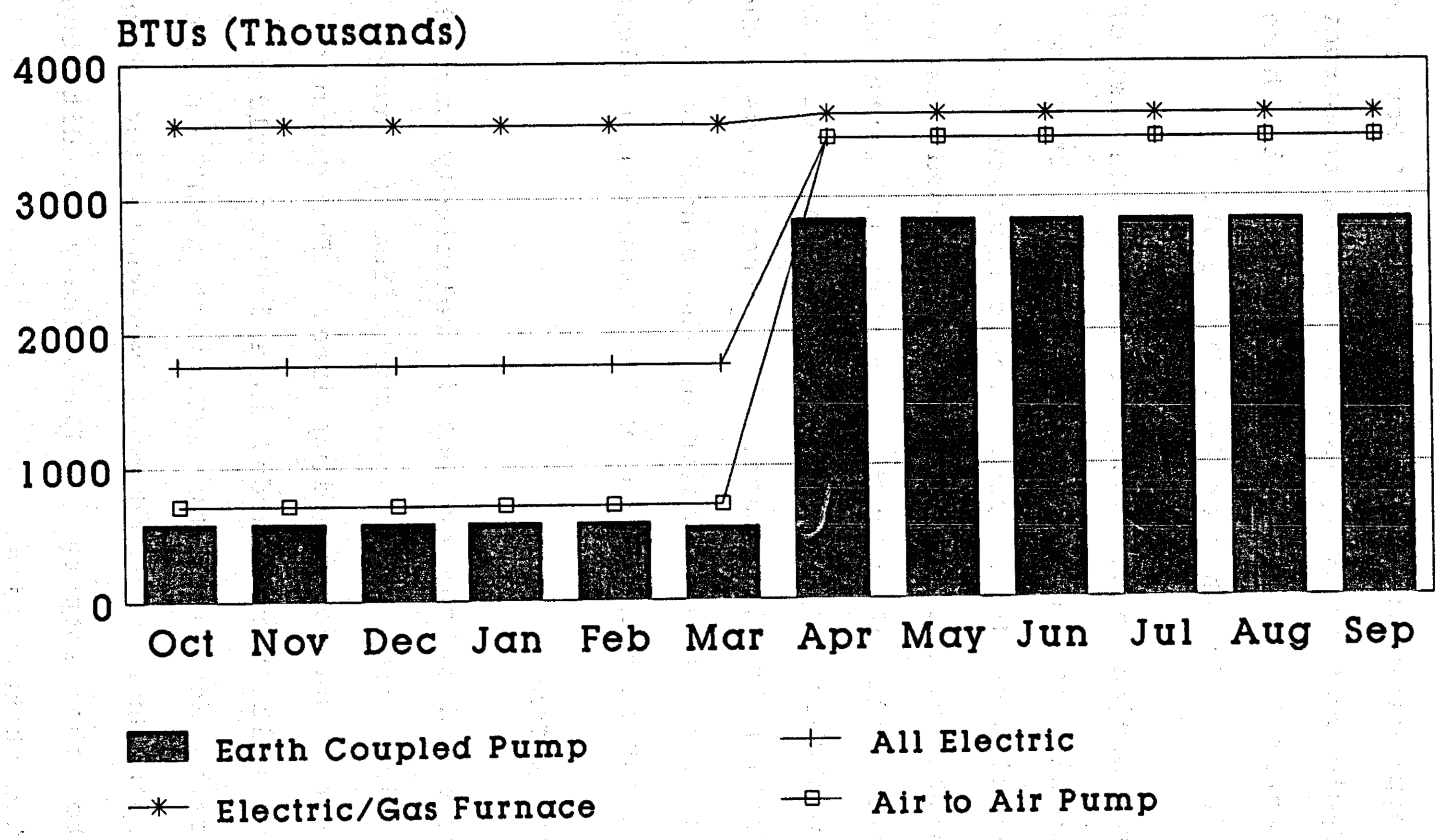


Figure 4

eight to ten year life expectancy of both the air-to-air and conventional units (See Table 1). Utilizing energy consumption rates applicable in the Houston Lighting & Power service area in a life cycle costing analysis based on new construction, the project staff estimated a positive cash flow for the home owner beginning early in the seventh year (See Figure 5).

The project staff anticipated that the cost of installation in a rehabilitation project would exceed that of a similar new installation by 40 to 75%. Rehabilitation costs are notoriously unpredictable, but the nature of proposed installation indicated that the costs of retrofitting with an earth coupled heat pump would probably vary in proportion to those of a more conventional installation in this case. In other words, the costs of the installation are a function of the condition of the house to be rehabilitated, rather than of the technology employed.

PROJECT DESIGN

The structure of the project is relatively straight forward: five residential units were selected from a group located in the Settegast Urban Homesteading Area. The group of units including the test units were awarded in a lottery held in the City Council Chambers on September 13, 1987 with great fanfare. Each program participant had received full screening for program eligibility prior to the lottery. Preliminary credit checks were also completed at this time.

The project team sought to identify typical units, that is neither the unit requiring the most rehabilitative work, nor the

The Theoretical Model

	New Construction Installation Conventional		Air to Air Pump (8-10 Year Replacement Required)		New Construction Costs Earth-Coupled Heat Pump (18 - 20 Year Replacement)*	
Installation	$2,000		$3,375		$5,250	
Operational Costs	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
Year 1	$822	$2,822	$656	$4,031	$540	$5,790
Year 2	$884	$3,706	$705	$4,736	$581	$6,371
Year 3	$950	$4,656	$758	$5,494	$624	$6,996
Year 4	$1,021	$5,677	$815	$6,309	$671	$7,667
Year 5	$1,098	$6,774	$876	$7,185	$722	$8,389
Year 6	$1,180	$7,955	$942	$8,127	$776	$9,164
Year 7	$1,269	$9,223	$1,012	$9,139	$834	$9,998
Year 8	$1,364	$12,587	$1,088	$13,603	$896	$10,895
Year 9	$1,466	$14,053	$1,170	$14,773	$964	$11,858
Year 10	$1,576	$15,629	$1,258	$16,030	$1,036	$12,894
Year 11	$1,694	$17,323	$1,352	$17,383	$1,114	$14,008
Year 12	$1,821	$19,144	$1,453	$18,836	$1,197	$15,205
Year 13	$1,958	$21,102	$1,562	$20,398	$1,287	$16,492
Year 14	$2,105	$23,207	$1,680	$22,078	$1,384	$17,876
Year 15	$2,263	$25,469	$1,806	$23,884	$1,487	$19,363
Year 16	$2,432	$29,901	$1,941	$29,200	$1,599	$20,962
Year 17	$2,615	$32,516	$2,087	$31,286	$1,719	$22,681
Year 18	$2,811	$35,327	$2,243	$33,529	$1,848	$26,528
Year 19	$3,022	$38,348	$2,411	$35,941	$1,986	$28,514
Year 20	$3,248	$41,596	$2,592	$38,533	$2,135	$28,514

* Initial cost includes installation of loop system which does not require replacement. Replacement of mechanical system is approximately the same as for a conventional unit.

NOTE: Replacement calculated for 8th and 16th year for conventional and air-to-air units. Costs are calculated at rates adopted in 1987. An annual increase of 7.5% is assumed for each future

Table 1.

LIFE CYCLE COST COMPARISON

New Construction

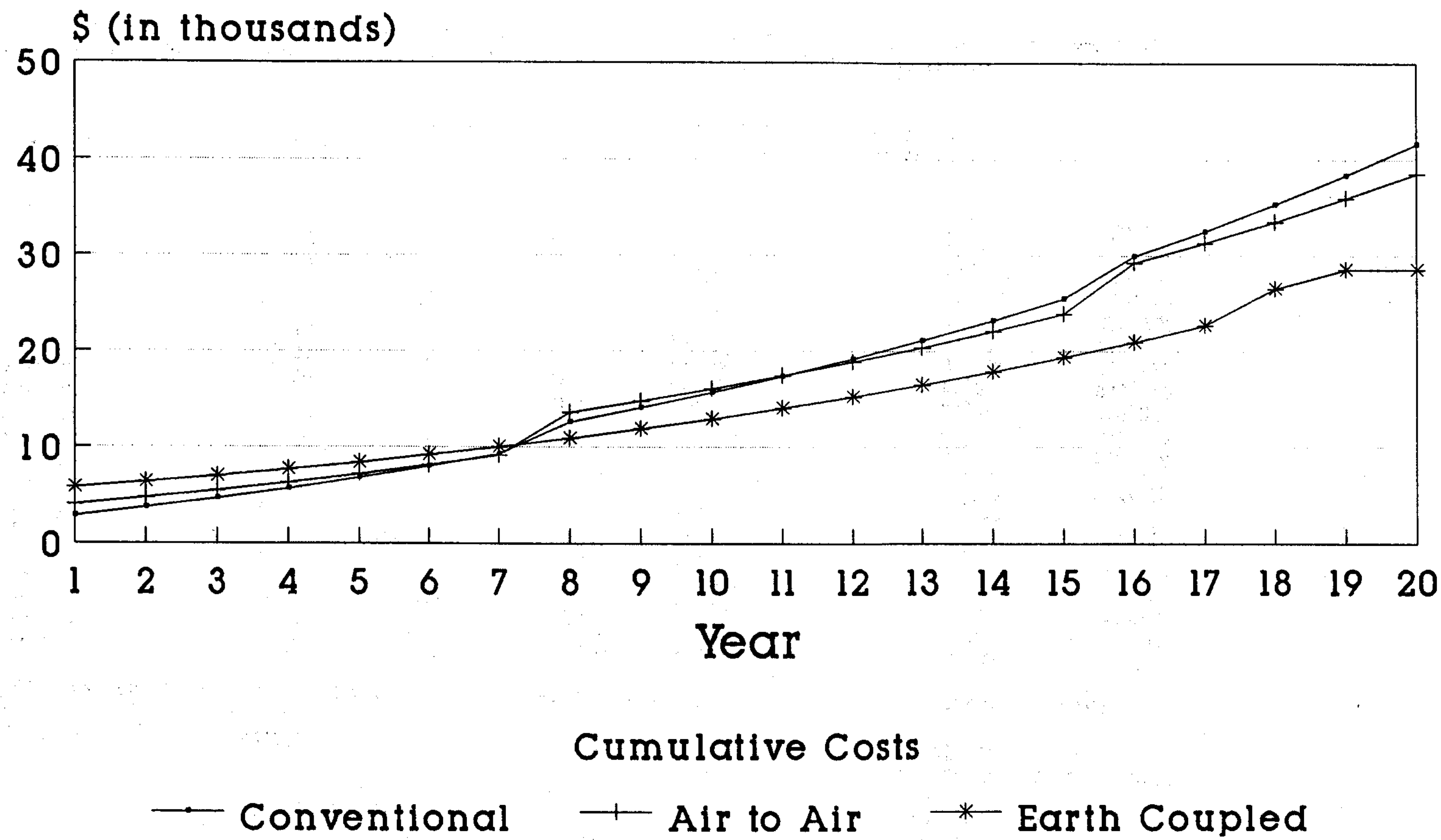


Figure 5

one requiring only cosmetic touch-ups. Each unit was paired with one or more units with the same type of construction (i.e. pier and beam, or slab) and approximately the same square footage. All-electric units were segregated from those using electric air-conditioning, and/or gas appliances, and natural gas heating. At the time of the lottery each unit had one or more control units which would be monitored for energy consumption as part of the test.

Each test unit selected was to receive the installation of an earth coupled ground source heat pump, reflective attic foil and R-40 attic insulation in addition to the conventional rehabilitation work. Each test unit was assigned a specific companion control unit which would receive conventional rehabilitation only. In order to ensure that all units were treated in exactly the same fashion, work orders were prepared on all units, and those selected for testing were subject to change orders after the initial work order had been prepared.

During the period in which work orders were being prepared, the project team began to focus on the nature and the characteristics of the program participants which were essential to the success of the project. All participants had been employed steadily over a period of years, had sufficient means to make payments on the rehabilitation loan and were current on all bills, including utility bills, personal notes and charge cards. Further, none had been more than thirty days late in making any payments during the five year period preceding the lottery. None of the participants had owned a home previously and although income eligible, were generally at the upper end of the "low-moderate" income bracket: the working poor. Several were single parents, and more than one family had an elderly parent included in the household.

Each family participated in the assessment of the requirements for rehabilitation, and certain elective improvements were approved. At this point the staff reassessed the decision concerning the units which would receive special treatment since it was clear that some program participants were better able to afford the costs of rehabilitation.

Once rehabilitative work was initiated, problems were identified with particular units: vandalism, termites and theft also entered the picture. The team assessed the estimated costs and benefits of the proposed project improvements to the originally selected home owner, revising the selection in some cases where it would be possible to effect a substantial reduction in costs to a home owner with a higher than average rehabilitation monthly payment while maintaining the integrity of the experiment itself.

Once this evaluation was complete, and the selection made, it became necessary to secure the approval of the home owner for the installation of the specialized equipment and improvements, and to ensure their participation in the project. Since the technology would be installed in their units at no additional cost, a "freebie" so to speak, all participants agreed to participate, although some were quite cautious in their acceptance. Many, if not all, of the participants who received the special improvements, appeared to have given the energy efficiency of their new homestead very little thought.

Having made the initial contact with the new homesteader, work continued as work orders were finalized and change orders for the test units were approved. Specifications for the design of the heat pump were released and bids solicited. The equipment was only available through a limited number of suppliers, and experienced installers were few, although a number of contractors expressed interest in the job. The project staff felt that the experiment could be jeopardized by the use of inexperienced installers, and elected to secure experienced work, albeit at a slightly higher total cost. Installation was overseen and approved by Public Works inspectors, who eventually issued certificates of occupancy for all units.

The installation of the equipment and rehabilitation work was a necessary preliminary to the actual test itself. Once the homesteaders moved into the unit the collection of data could begin. Data was to be collected on a monthly basis from both the gas and electric utility. Actual consumption for both gas and electric service would be converted to units of energy, and the consumption of test and control units would be evaluated. It was acknowledged that the data might require some manipulation to adjust for family size and thermostat settings.

The performance of all units was to be compared with that of the theoretical model, and the financial feasibility of a large scale implementation program would be evaluated, using certain assumptions concerning initial costs, economies of scale and consumption control policies.

The project staff hypothesized that the test units would significantly outperform the control units over a period of time which was sufficiently short that the effect of the higher initial cost component could be mitigated with a project of optimal size. Determination of that optimal point would be the focus of establishing a strategy for incorporating innovative technologies into large scale rehabilitation projects, partly on the basis that the technology evaluated in this study was now proven, rather than experimental.

SUMMARY OF RESULTS

On the average, test units outperformed control units over the twelve month period by an average of 19.3 million BTUs or approximately 25.3%. Surprisingly enough, the greatest differences in energy consumption between the control and test units occurred during the winter months of December, January and February. During the months when the weather was the most moderate, in the fall (October and November) and the spring (April, May and June) the average consumption for both types of units was similar, with control units actually outperforming the heat pump units in one month. The bar graphs in Figure 6. compare the average energy consumption of the five test units with the control home average. The performance of both groups is measured against that predicted by the theoretical model which is shown in linear form.

Averages are deceptive, however, particularly where the number of households actually included in the experiment is so small, and the outcome subject to many extraneous variables. Actual energy consumption during the winter months contradicted the results predicted in all cases. It was assumed that consumption would be greatest in the months where cooling was required. This was not the case for any of the units included in the study. The results did confirm the relative efficiency of the earth coupled heat pump in effecting energy savings when compared to conventional units, demonstrating relatively greater savings than those experienced during the summer months.

EARTH-COUPLED HEAT PUMP
Comparison of Average Consumption

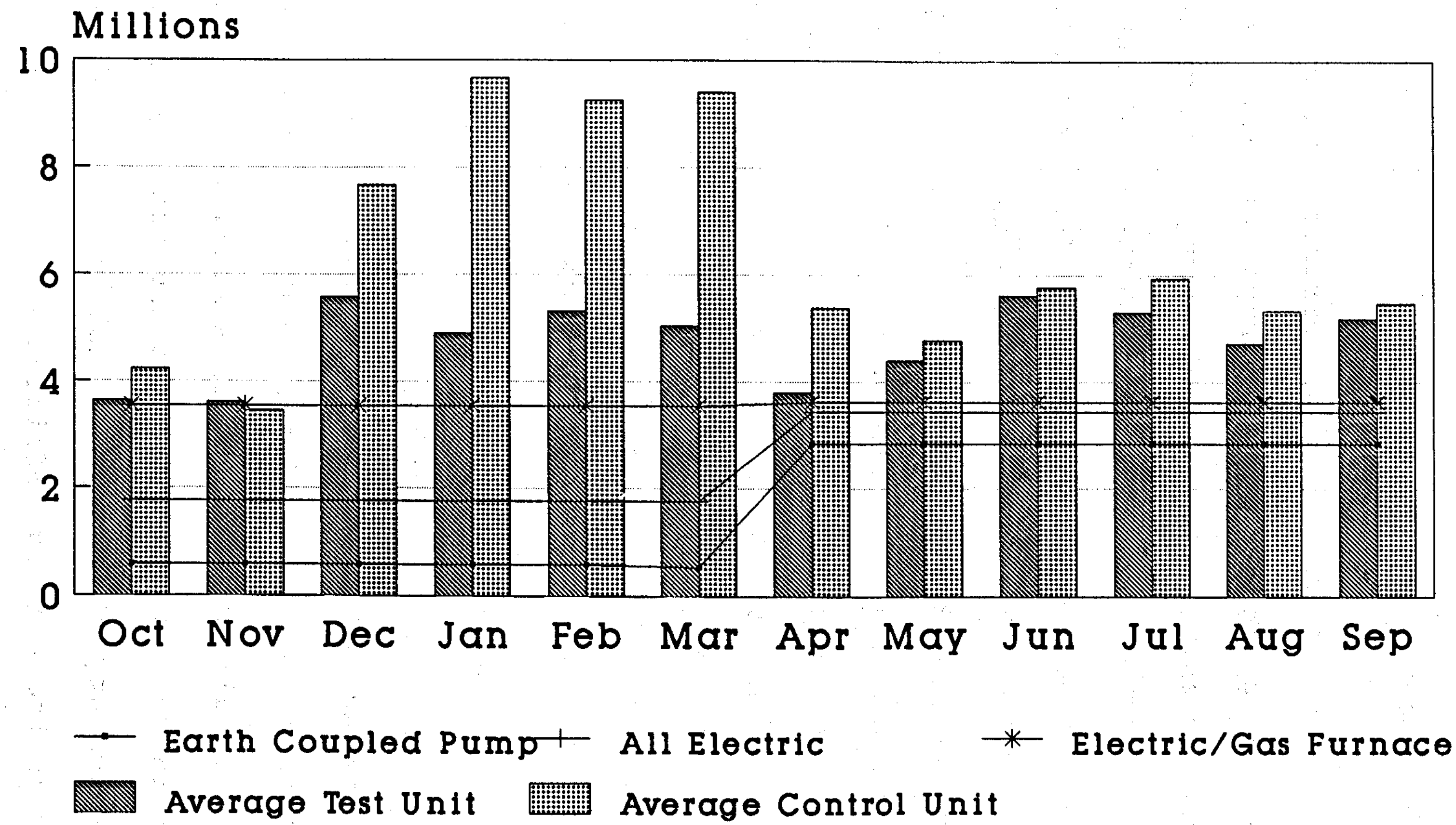


Figure 6

Most surprising was the relatively large amount of energy consumed in the production of hot water for those units where this could be isolated (See Table 2.) Four units were equipped with gas water heaters, one of which (control unit in Group 5) also had a gas furnace. Although the test unit in Group 5 registered a negligible amount of usage never in excess of ten percent, both the test and control units in Group 2 registered energy consumption for production of hot water and cooking, which ranged between 20% and 85% of all energy consumed. (See Figure 7.)

The "average" results do not reflect the wide variation in results for individual pairings, a finding which underscores the limitations of the small size of the sample.

Individual unit consumption, and performance of the test unit relative to the control unit appear to have been affected by the move-in date, the personal preferences of individual family members, the general composition of the family unit, and their experience in home maintenance. Each group, a test unit and a control unit, is analyzed individually, and is compared with the results predicted by the theoretical model. The energy consumption data which forms the basis of this analysis is contained in Appendix A.

GROUP 1 COMPARISONS

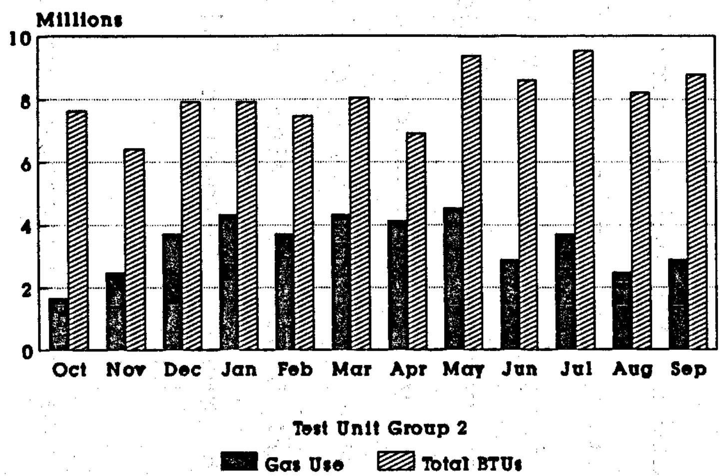
The test unit located at 9247 Laura Koppe has 1,341 square feet of area. Originally a three bedroom unit, the attached garage has been converted into a den off the living room. The unit has brick

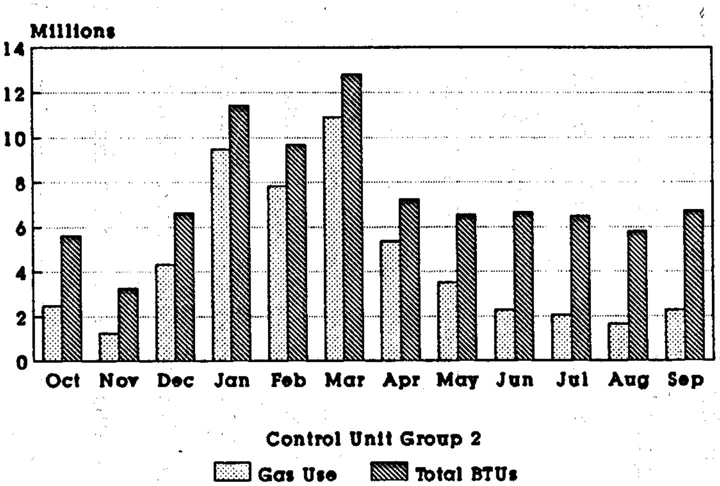
THE EARTH-COUPLED HEAT PUMP

Gas Water Heater Comparison
(in BTUs)

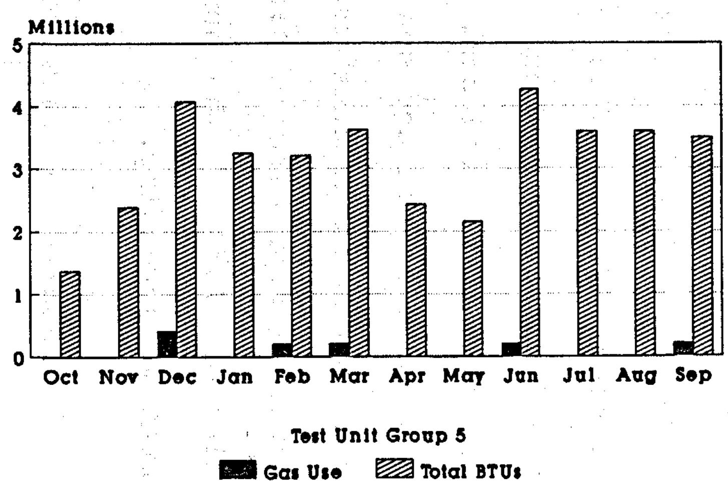
Service Date	10/88	11/88	12/88	1/89	2/89	3/89	4/89	5/89	6/89	7/89	8/89	9/89	Total
Averages													
Test	824,000	1,236,000	2,060,000	2,163,000	1,957,000	2,266,000	2,060,000	2,266,000	1,545,000	1,854,000	1,236,000	1,545,000	21,012,000
Control	2,060,000	1,545,000	4,017,000	9,682,000	7,725,000	11,227,000	5,665,000	2,987,000	2,060,000	1,854,000	1,545,000	1,957,000	52,324,000
Group 2													
Test	1,648,000	2,472,000	3,708,000	4,326,000	3,708,000	4,326,000	4,120,000	4,532,000	2,884,000	3,708,000	2,472,000	2,884,000	40,788,000
Control	2,472,000	1,236,000	4,326,000	9,476,000	7,828,000	10,918,000	5,356,000	3,502,000	2,266,000	2,060,000	1,648,000	2,266,000	53,354,000
% Total Usage													
Test	21.59%	38.57%	46.85%	54.63%	49.63%	53.86%	59.56%	48.38%	33.49%	38.84%	30.15%	32.87%	42.14%
Control	44.06%	38.06%	65.34%	82.98%	80.91%	85.25%	74.07%	53.54%	34.05%	31.85%	28.41%	33.74%	60.09%
Group 5													
Test	0	0	412,000	0	206,000	206,000	0	0	206,000	0	0	206,000	1,236,000
Control	1,648,000	1,854,000	3,708,000	9,888,000	7,622,000	11,536,000	5,974,000	2,472,000	1,854,000	1,648,000	1,442,000	1,648,000	51,294,000
% Total Usage													
Test	0.00%	0.00%	10.13%	0.00%	6.42%	5.69%	0.00%	0.00%	4.82%	0.00%	0.00%	5.91%	3.30%
Control	96.99%	77.13%	74.89%	91.12%	87.84%	91.37%	85.70%	62.79%	39.83%	40.03%	37.03%	37.63%	74.17%

Table 2.





GAS HEAT/WATER & APPLIANCES



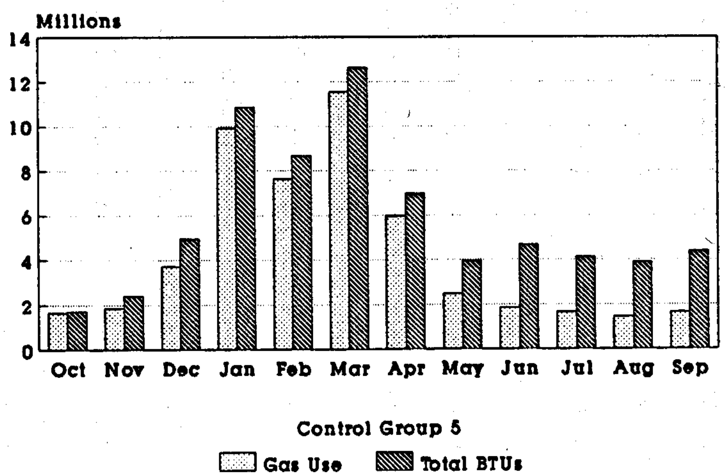


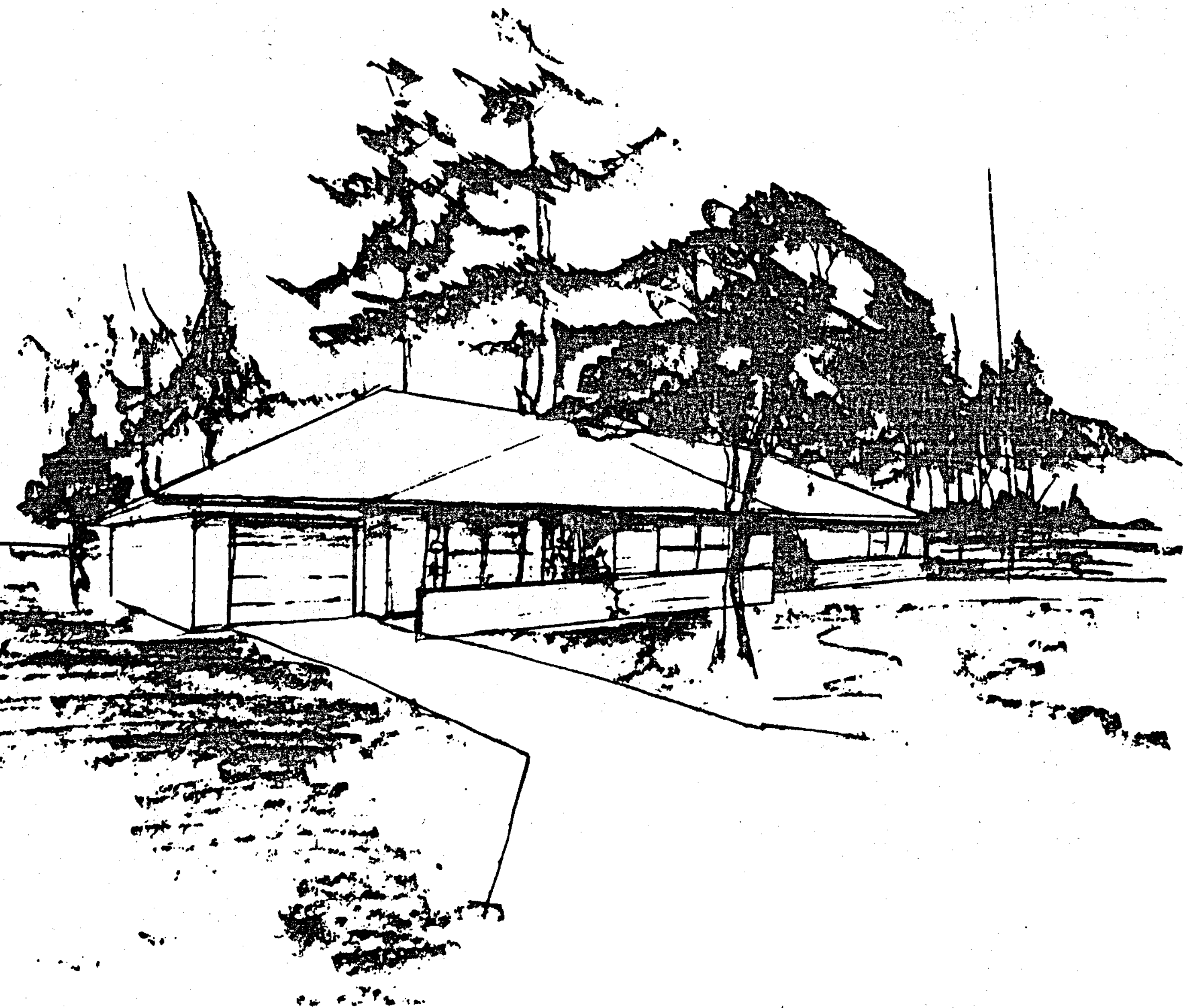
Figure 7

veneer and is home to a family of two, a single female parent and her preschool daughter. At the request of the homesteader, a first time home owner, ceiling fans were installed in each bedroom and in the dining room. The front of the house is oriented to the south, and several large trees provide shade in the back yard. The thermostat is reported to be maintained at a constant 75^{o}F except when the home owner is at work.

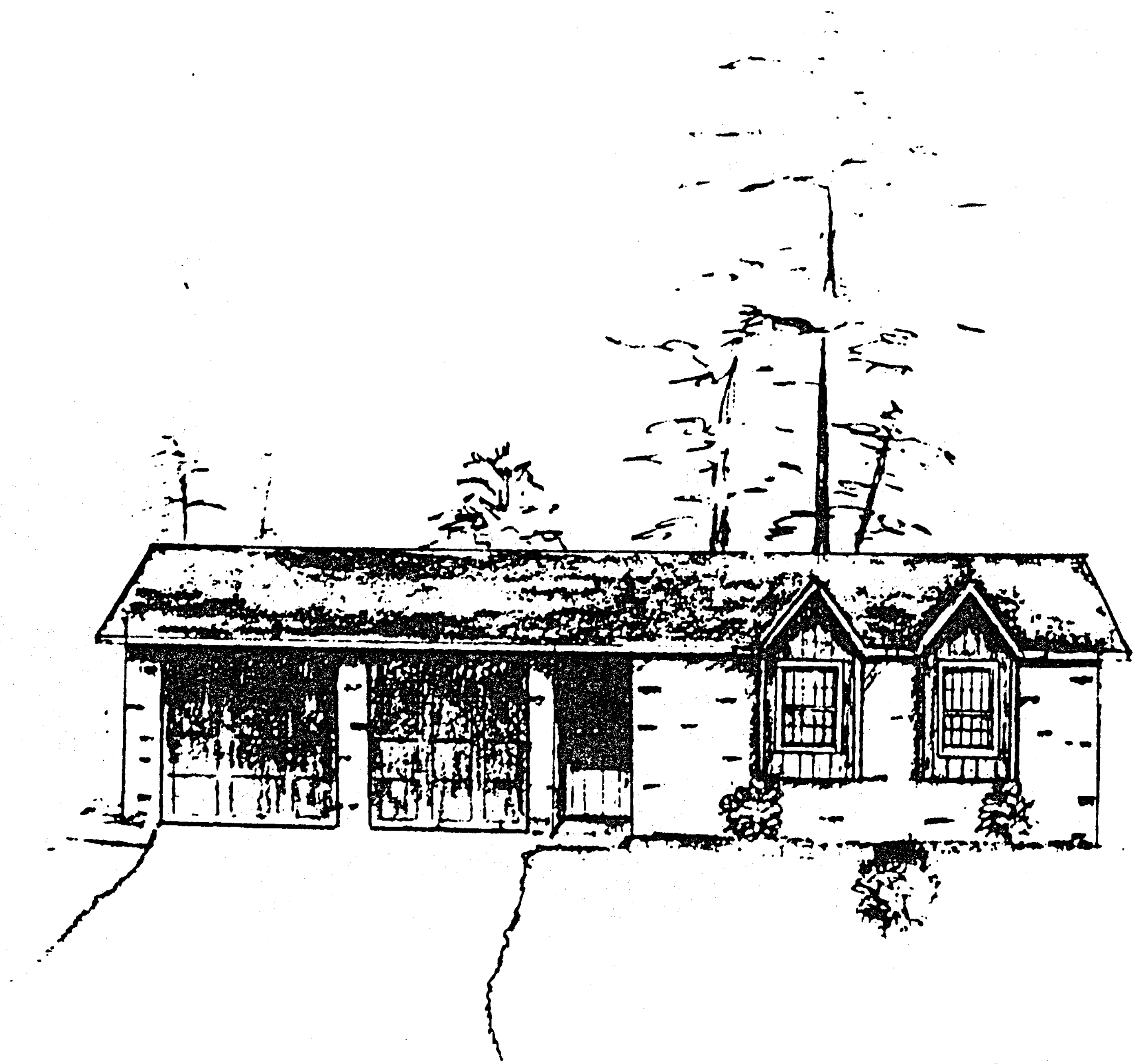
Our interview with her in September 1989 indicated that she was not aware that the filters required frequent changing for maximum performance. This may account for the fact that although the heat pump and other improvements recorded a substantial energy savings during the winter months, the first months of residence, this performance was substantially worse than that of the conventionally equipped control unit during the summer months.

The control unit was slightly larger, including approximately 1,419 square feet, with four bedrooms, two bathrooms and an attached garage. Ceiling fans were installed in the living room and in the master bedroom. The three member family includes two adults and a school age son. This family was also described as in need of home maintenance training. They reported that the system was turned down between 8:00 a.m. and 5:00 p.m. with an in-use setting of 78^{o}F. The unit has a western exposure with no vegetative screening.

The results of this comparison are contradictory, since the initial energy savings appear reversed during the summer months. (See Figure 8.) The amount of energy consumed by the test unit was 41% less than the control unit during the months of February, but



Group 1 - Test
9247 Laura Koppe



Group 1 - Control
9806 Kerry Glen

EARTH-COUPLED HEAT PUMP

Group 1 Comparison

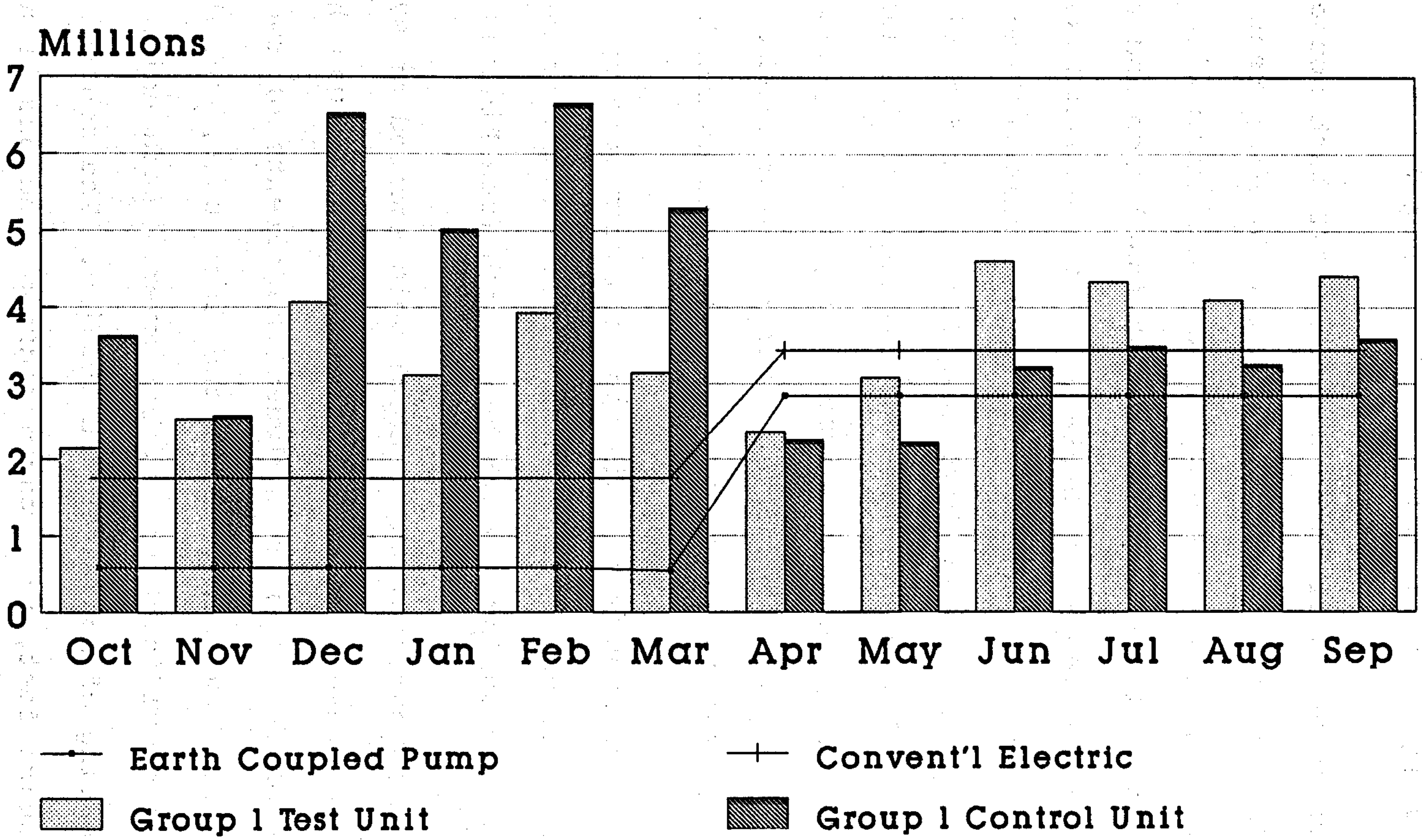


Figure 8.

43% more than the same unit in June, four months later.

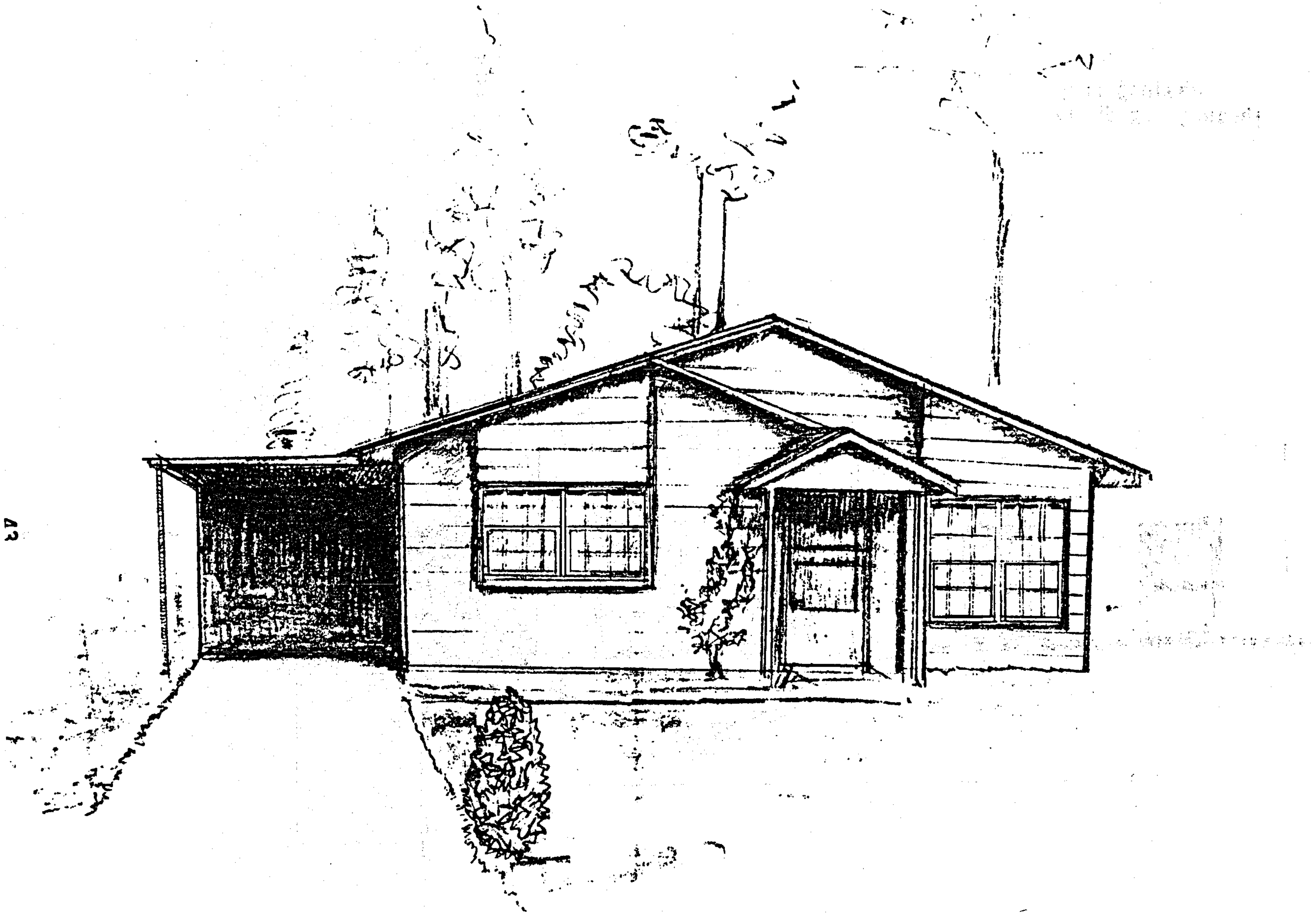
GROUP 2 COMPARISONS

This relative small three bedroom 1 1/2 bath house of 1,040 square feet is also homesteaded by a single female parent with a preschool daughter, although a teenage niece also lives with the family. The house is built on a concrete slab foundation and has exterior wood siding and a gas water heater. A ceiling fan was installed in the living room. The homesteader reports that the thermostat is set at 74°F when she is at home and 80°F at other times, and she is apparently knowledgeable about the need for frequent changes of the filter. This unit is unique in reporting operating trouble with the unit and the thermostat, probably attributable to the lack of a roof-top ventilator which causes the unit to run hot.

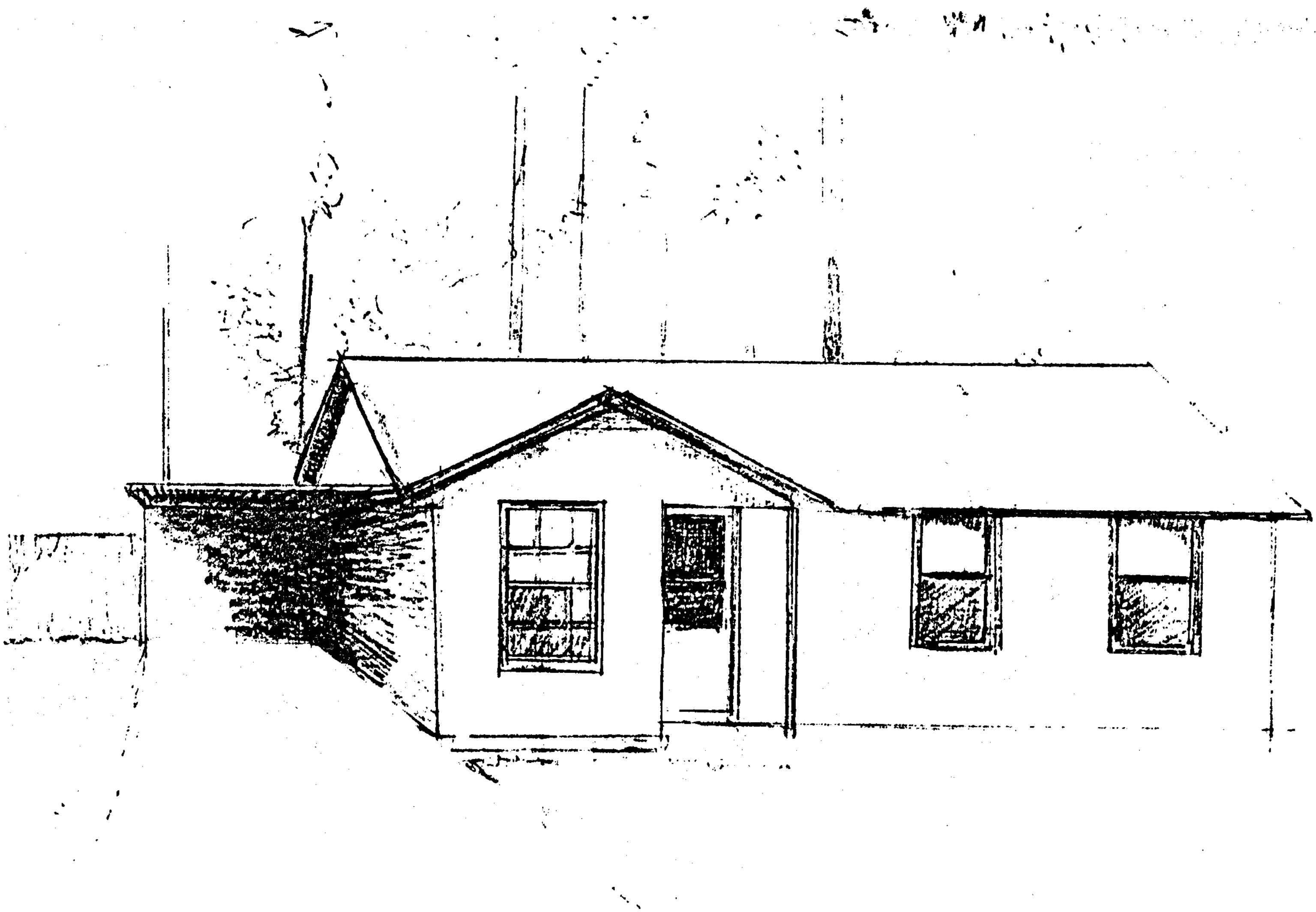
The test unit in this case consumes more energy that the conventional unit, registering between 97.34% more in October, but 32.68% less during the month of March (see Figure9.).

In comparison, the control unit located at 9731 Courben which received conventional rehabilitation only, was homesteaded by a family of four, which included the parents of two young children, ages three and six. Like the test unit, the house faced east without significant vegetative cover. Both units used natural gas for heating of hot water and cooking. The control unit consists of 936 square feet, with three bedrooms and one bathroom. A ceiling fan was installed in the living room.

The parents work different shifts, maintaining the thermostat at a temperature of 70°F - 75°F during the day and eighty at night.



Group 2 - Test
9727 Courben



Group 2 - Control
9731 Courben

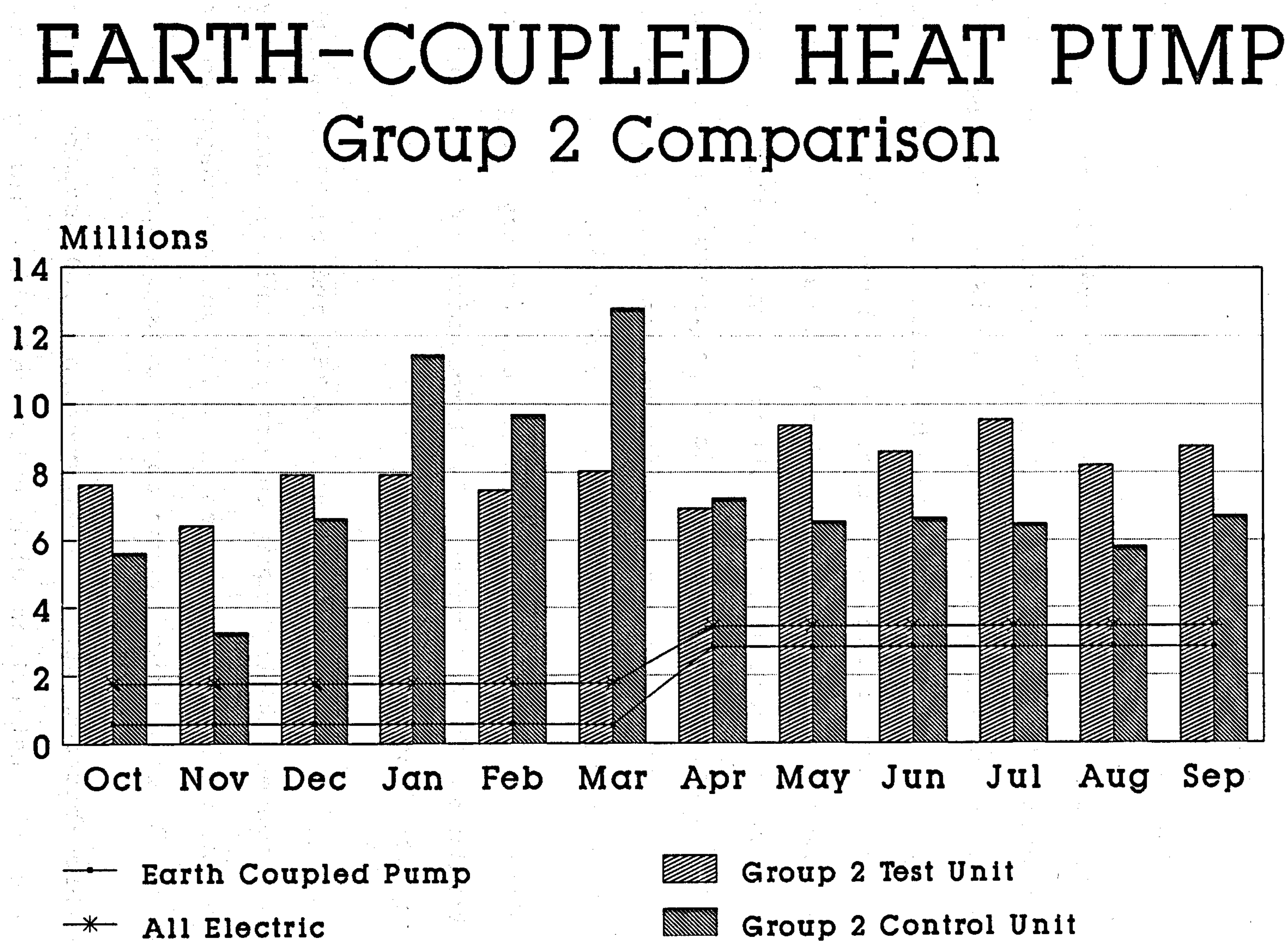

EARTH-COUPLED HEAT PUMP
Group 2 Comparison
Millions
14
12
10
8
6
4
2
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Earth Coupled Pump
All Electric
Group 2 Test Unit
Group 2 Control Unit

Figure 9

The heating and cooling units are normally turned off between 11:00 p.m. and noon. The energy bill was found to be roughly comparable to what they had paid earlier.

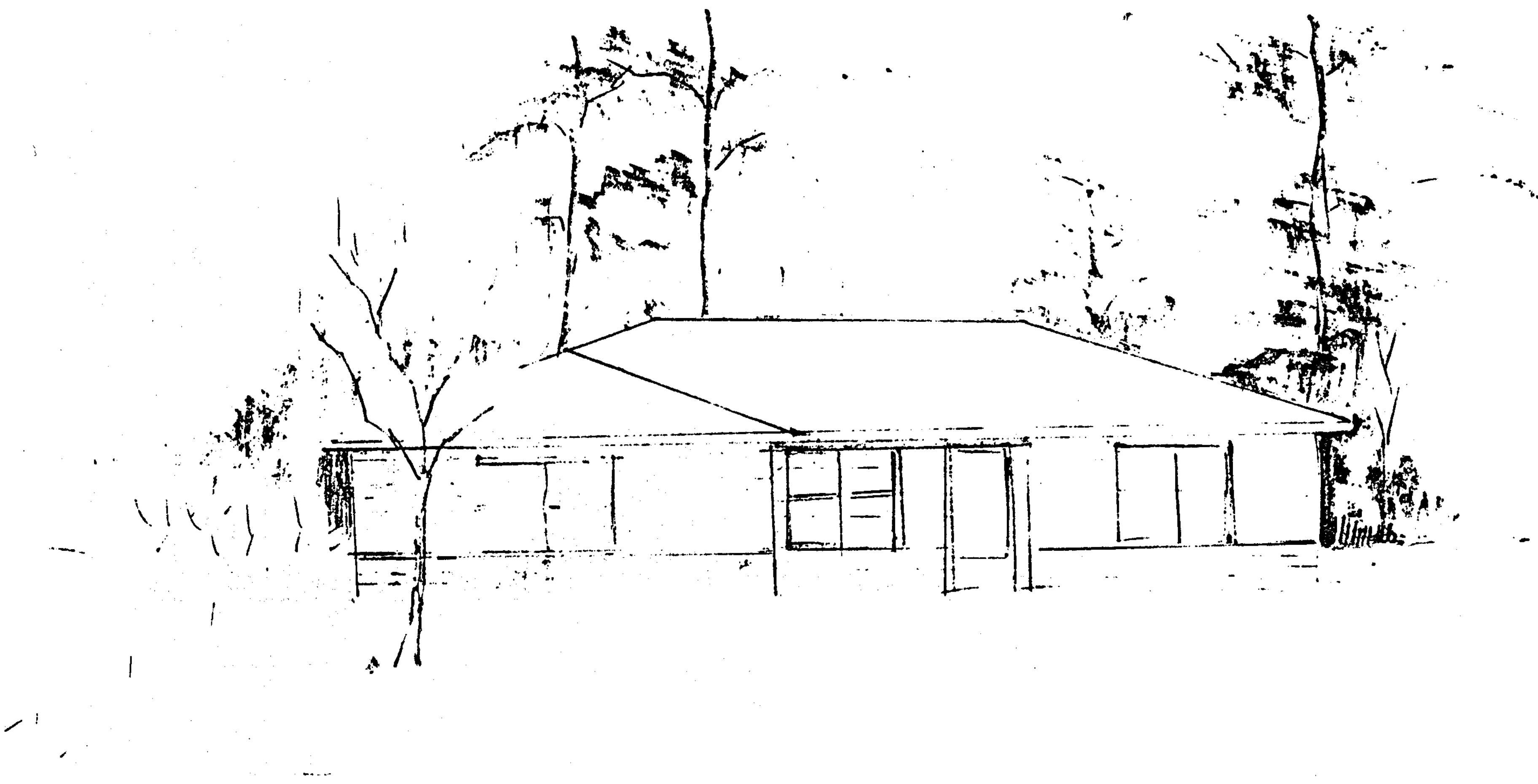
GROUP 3 COMPARISONS

The performance of this unit was substantially more in line with that predicted by the model. This all-electric three-bedroom home has wood-siding and is constructed on a slab. Equipped with a heat pump, reflective attic foil and additional insulation in front of the house faces north and does not have any protective vegetative cover. The homesteading family consists of two adults and two elementary school aged children, who routinely change filters every three months. The ambient temperature is maintained between 72^{o}F and 80^{o}F, and the temperature is reduced during the normal working hours when the family is not at home.

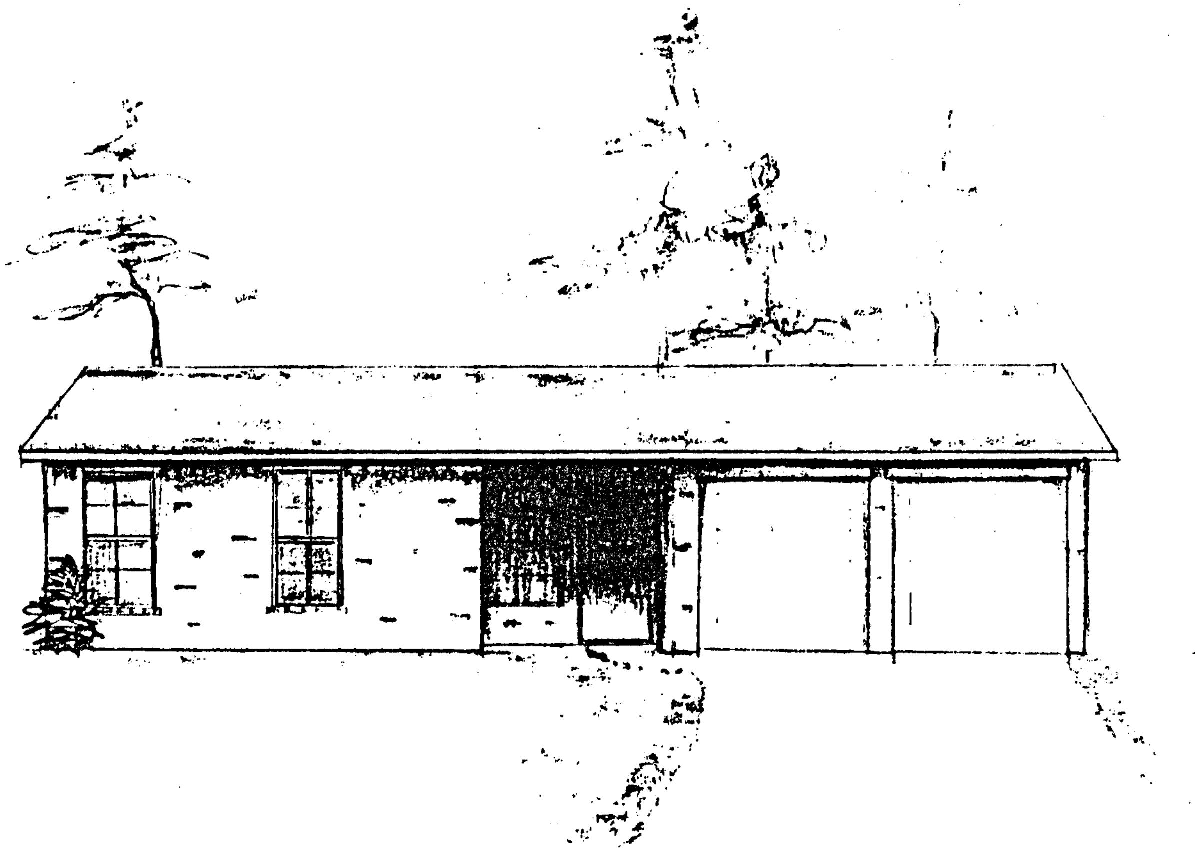
Although they report paying more for electricity and gas, this may be attributed to the relatively large size of this unit in comparison with most apartments.

The energy consumed was between 28.36% and 54.99% less than that of the conventionally equipped control unit located at 9831 Kerry Glen in any month, with an average annual usage for the period of 38.04% with which it was compared (See Figure 10.).

The three-bedroom control unit contains 1,600 square feet and is also a slab construction with brick and vinyl siding with an eastern exposure and little cover, although the attached garage is located on the north. The single female parent has a teenage daughter and son, and a younger son who is eleven. This family



Group 3 - Test
9038 Laura Koppe



Group 3 - Control
9831 Kerry Glen

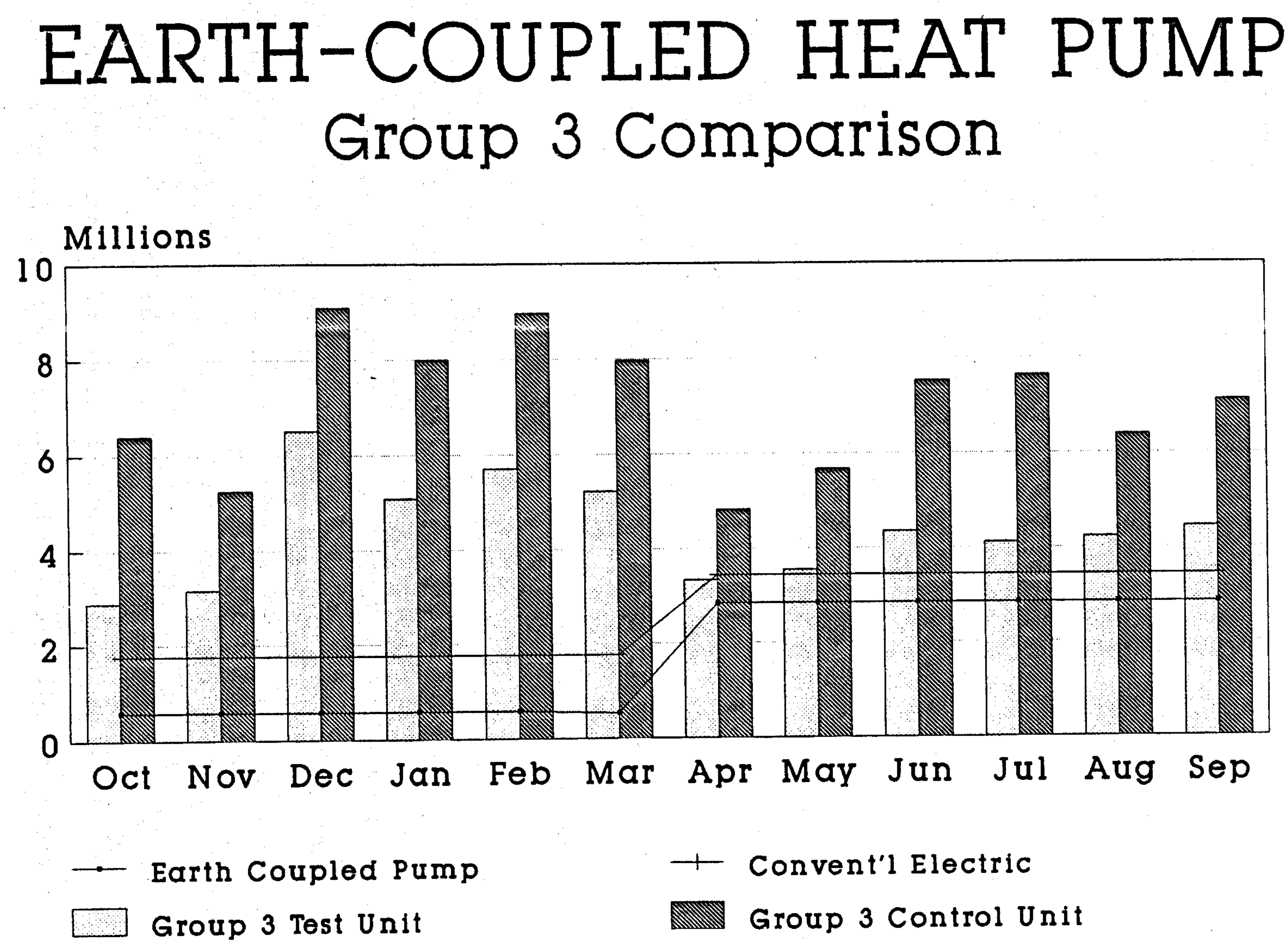

EARTH-COUPLED HEAT PUMP
Group 3 Comparison
Millions
10
8
6
4
2
0
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Earth Coupled Pump
Convent'l Electric
Group 3 Test Unit
Group 3 Control Unit

Figure 10

reported no significant difference in their utility bills, even though the thermostat was maintained at 78°F during the day, and turned off during the evening hours.The homesteaders replace system filters on a monthly basis. Like the test unit in Group 2, this household includes teenagers, who are likely to be home during the summer months, and who are also less tolerant of higher temperatures during peak cooling periods. It seems likely that the problems reported in both places may bear some relationship to the age of the family members, something most parents would agree with intuitively.

Unlike the consumption of the units included in Groups 1 and 2, the rate of savings registered by the test unit in comparison with the control unit remained relatively constant over the entire period, with only minor fluctuations in individual months.

GROUP 4 COMPARISONS

The overall results of the comparison in Group 4 are similar to those of Group 3. The test unit substantially outperformed the conventional unit by 38.01% for the period (See Figure 11.), a result surprisingly consistent with the results of Group 3. In this case, the owner of the test unit was enthusiastic concerning the performance of the heat pump which she compared to a window unit at her previous residence. A large 1,598 square foot all electric unit with three bedrooms and 1 1/2 bathrooms, this unit houses five people including the homesteader's mother (aged 53) and three adolescent children. The house has an eastern exposure and no natural shading.

EARTH-COUPLED HEAT PUMP

Group 4 Comparison

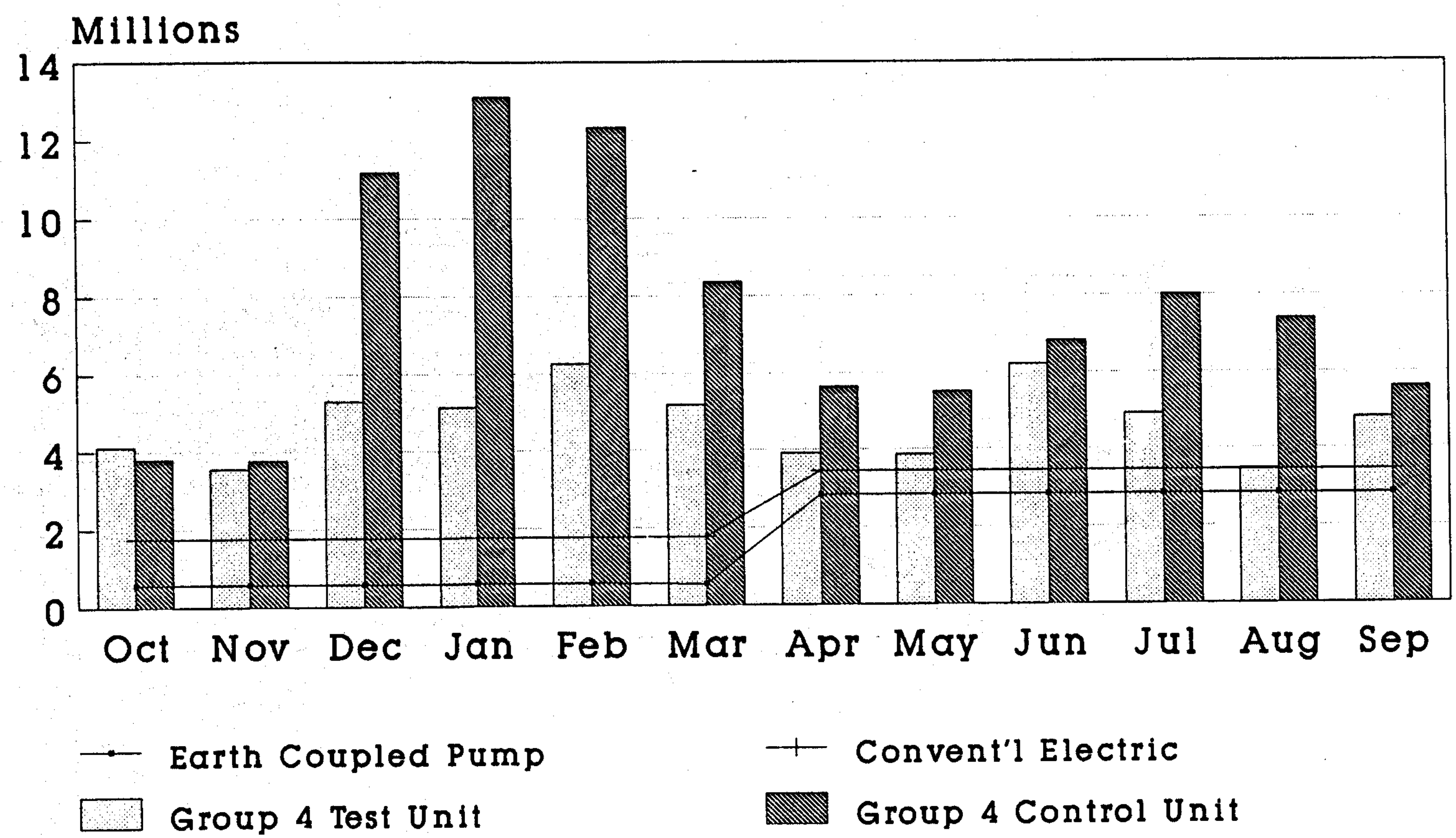
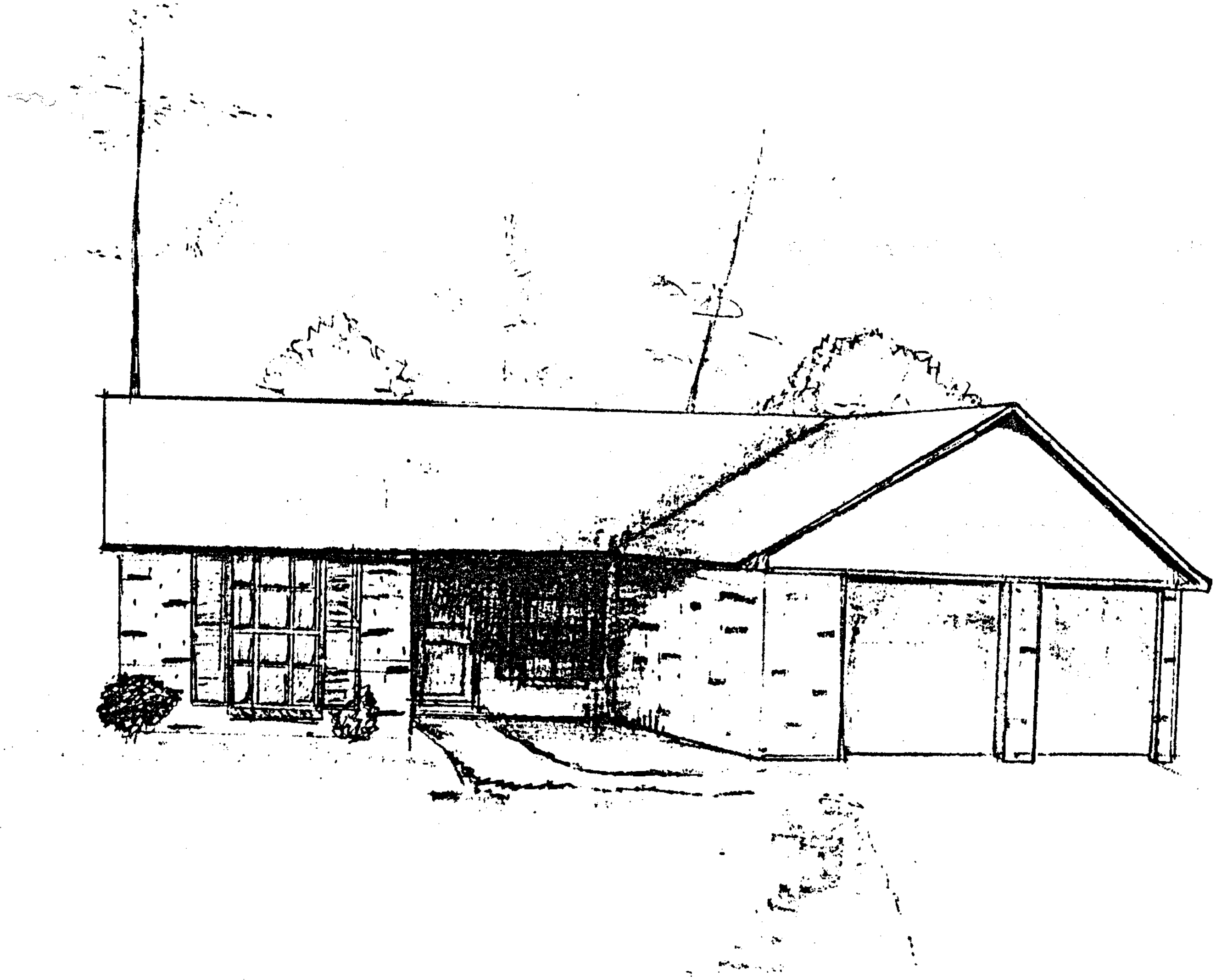
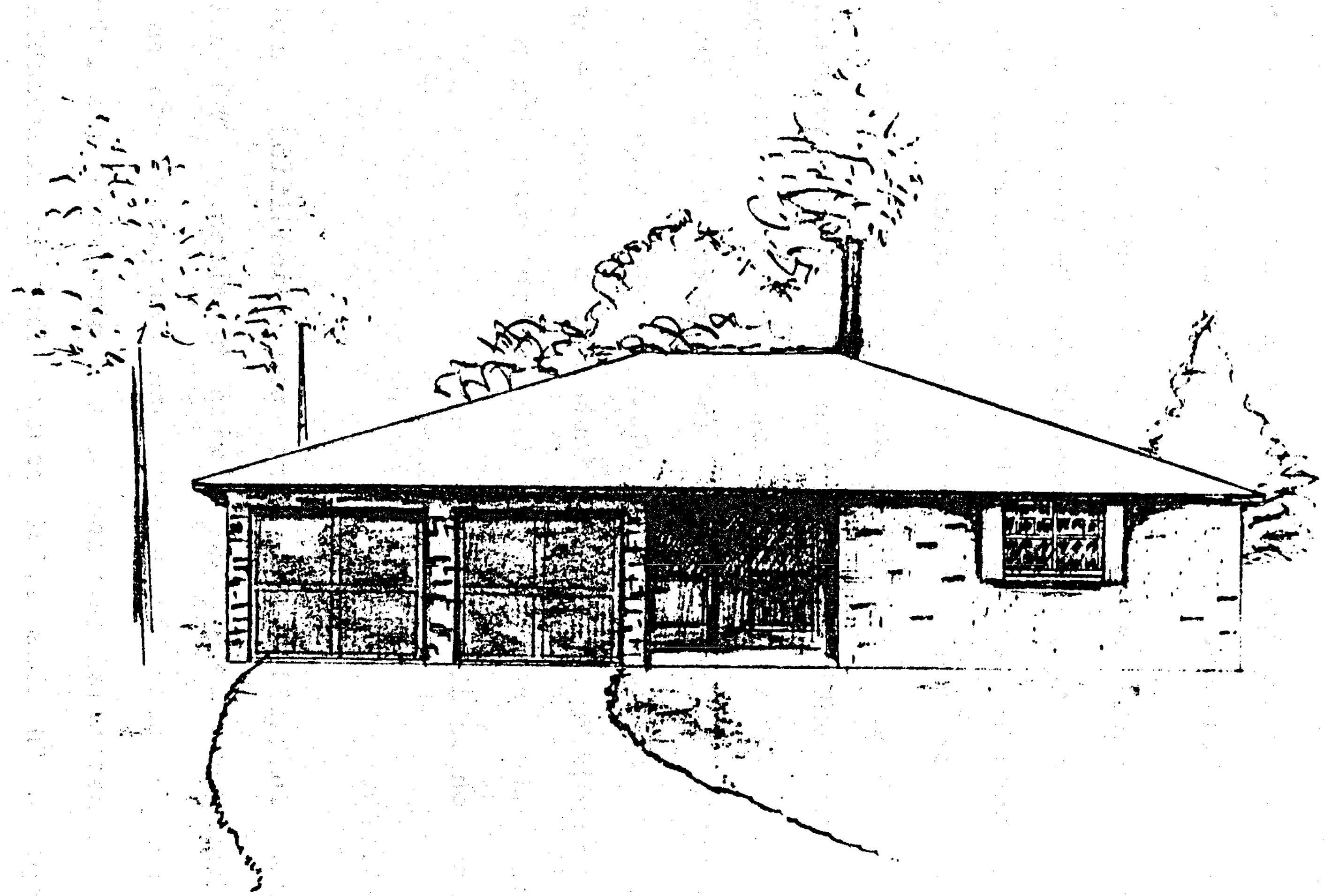


Figure 11



Group 4 - Test
9815 Kerry Glen



Group 4 - Control
9843 Kerry Glen

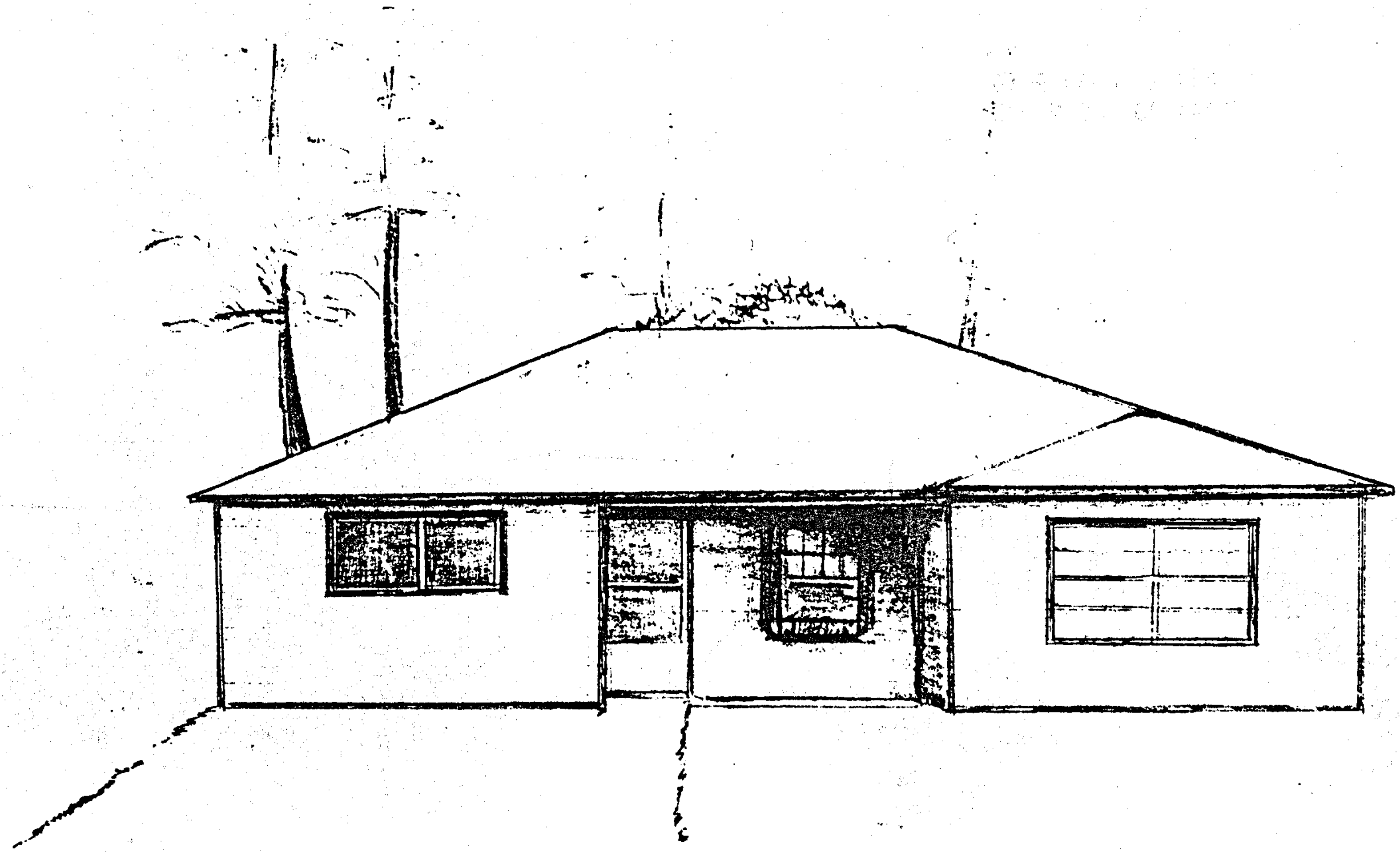
The homesteader of the test unit reports that the system is turned off in the day between 8:00 a.m. and 5:00 p.m. while the family is not at home, and the thermostat is maintained between 75°F and 80°F. Filters are replaced once every six months.

The conventional unit located at 9843 Kerry Glen is also all electric, and although filters are changed once a month, the homesteader reports that her bill is approximately seventy-five dollars higher than that at her previous residence.

Although the system is reportedly turned off during the time the homesteader is at work, her dependent family members include an elderly parent (aged 70) and an adult daughter (aged 25) who share the 1,600 square foot, three bedroom two-bath unit. Like Groups 1 and 2, the greatest energy savings occur during December, January and February, when heating rather than cooling is required. In contrast to the relatively stable monthly differential noted in Group 3, the deviation between test and control units fluctuates substantially from month to month. Only in the month of October, however, may the difference be attributed to a difference in unit occupancy, since the homesteader in the control unit did not take physical possession until October.

GROUP 5 COMPARISONS

This unit was initially in very poor condition, and was subsequently found to be infested with termites. The attached garage had been converted to a den, and was maintained as such, even though a substantial portion of the structure was rebuilt. Energy consumption in this 1,320 square foot is reasonable when



Group 5 - Test
9109 Laura Koppe

Group 5 - Control
9105 Laura Koppe

compared with both test and control groups of the same size. The female single homesteader was unable to make comparisons between previous energy usage since she had had no heating or cooling system at all in her previous residence. She is meticulous in cleaning or replacing system filters, however, although the thermostat is maintained at 78^{o}F most of the time. Ceiling fans were installed in the living room and bedrooms. Built on a concrete slab with wood siding, the house faces south with vegetative cover on the north. Hot water and cooking heat is supplied by natural gas.

The control unit in this Group, located at 9105 Laura Koppe, is perhaps the more unusual of the two units. A husband and wife who both work are careful to turn the thermostat up to 85^{o}F in the summer when they are not home, turning it down to 75^{o}F while at home. The homesteader estimates that the utility bills have increased by $25-$35 in the winter and by about $65 during the summer, although the comparison is made with the costs of heating and cooling a small apartment. The house is oriented to the south, with relatively little natural shading. No surprisingly perhaps, this house relies more on the use of natural gas than any other house included in the study, because in addition to hot water, winter heating is provided by a gas furnace, even though all cooking appliances are electric.

Figure 12, shows that the test unit outperforms the control unit, although by a much smaller percentage than that realized by Group 3 or 4. This is probably attributable to the small size of the family unit homesteading the control unit, where both adults

EARTH-COUPLED HEAT PUMP

Group 5 Comparison

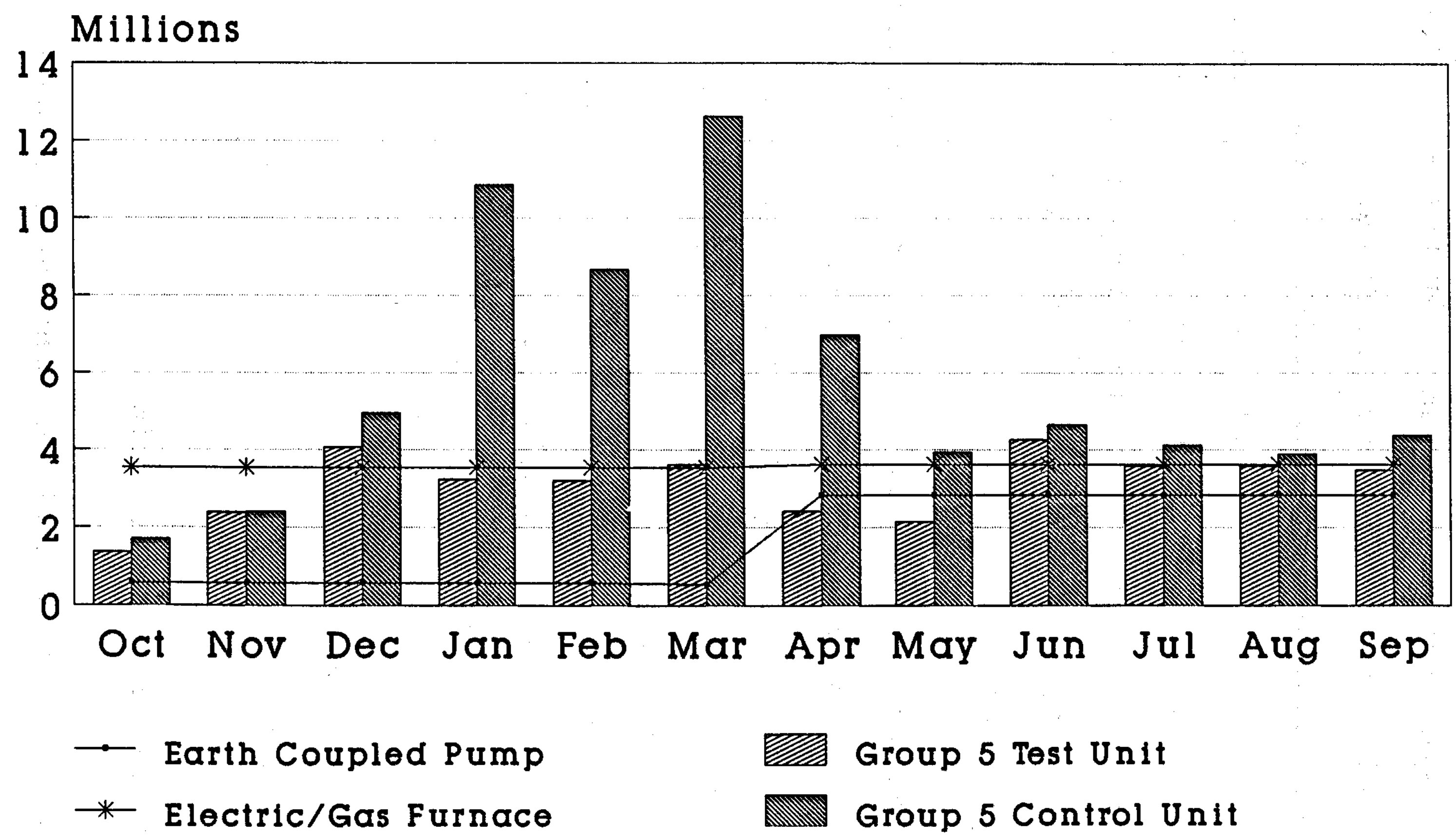


Figure 12

are energy conscious and absent during the day.

CONCLUSIONS

From the standpoint of conserving energy alone, the earth-coupled heat pump is unquestionably an effective tool with which to reduce overall energy demand in the Houston metropolitan area. The average energy savings of even this small sample clearly make the use of the heat pump in housing strategies a viable energy conservation option. It is also clear that a linear increase in savings will result for each additional housing unit properly equipped. It is also apparent that greater savings could be achieved by the installation of the desuperheater for hot water production which was not included in our evaluation.

From a pragmatic standpoint, however, the initial cost and maintenance of the earth coupled pump must be assessed. If the capital costs cannot be amortized in actual savings by individual home owners on their monthly utility bill, the incentive to install the technology does not exist, and energy conservation opportunities are therefore lost. The cost model for new construction, which was utilized as the basis for determining the initial feasibility of the project, provides a useful framework for assessing the long term practical applications of the technology in the context of single family housing rehabilitation. Incorporating the assumption that once the technology departs the realm of the experimental and becomes the norm, certain economies of scale in manufacture and installation are predictable, the reduction in unit cost being a function of the number total units so equipped. The optimal strategy would define the point at which maximum overall dollar savings, measured in total project dollars, would coincide with the greatest aggregate energy savings. Factors establishing this point of optimality include the prevailing rate per BTU of energy consumed, the cost of the manufactured heat pump, and labor costs associated with installation which may depend on union rates, and the rate of decline in overall costs which acceptance of the technology may provide.

Chapter 4 evaluates these cost considerations under conditions and rates existing in the Houston area. Because the analysis is performed on a per unit basis, it may be adapted to rate structures and conditions applicable to other areas. The thermal efficiency results of the study probably may be applied with only minor additional modifications in subtropical and temperate coastal areas of the United States, since the climatological conditions in the Houston area, including heat and humidity, represent extreme conditions: the worst case scenario from an energy consumption standpoint.

CHAPTER 4 - FINANCIAL CONSIDERATIONS

THE COST

There is a wide variance between the relatively predictable costs of new construction, and the costs of housing rehabilitation. Rehabilitation often includes requirements for improvement in electric service, structural repair, venting and eradication of infestations which never arise in the context of new construction. Often the repair comes as a surprise once the rehabilitation project is already well underway.

The experience of the project staff in undertaking this study confirmed this as applied to the installation of the earth coupled heat pumps. The average per unit cost of installation at $9,219 was approximately 76% higher than that estimated for new construction. Under the assumption that installation of more conventional technology would also vary between 40% and 75% more than that for a new unit and proportionate to that of the earth coupled heat pump, the initial cost was adjusted upwards to an average of 75% greater than a new unit for both a conventional and air to air pump.

Actual heating and cooling costs are based on those projected by Houston Lighting & Power, using present rates, which were adopted in 1987. The differences in monthly costs were calculated using the S.E.E.R. coefficients applicable to the type of unit, assuming that an average rate increase of 7.5% was likely for every year of the 20 year period analyzed. Also factored into the analysis was the replacement cost of individual units based on life expectancy.

In this regard, the earth coupled system has a distinct advantage over the conventional and air to air systems, since the life of the earth coupled unit is more than double (18-20 years) that of the other systems (8-10 years). Even so, replacement of the mechanical portion of the system is roughly equal to that of the conventional unit, since the relatively expensive underground lines are permanent if properly maintained.

This analysis indicates that, like the results for new construction, the total cost of the various units is equal at some time between the seventh and eighth year. Coincidentally, replacement costs were included in the eighth year for purposes of our analysis. Substantial dollar savings after this point accrue to the benefit of the unit with an earth coupled heat pump installed. (See Figure 13.) Over a twenty year period, these dollar savings are estimated to exceed $6,400 when compared to an air to air pump, and $8,400 when compared to a conventional heating and cooling system. (See Table 3.)

Using the assumption that the per unit costs of rehabilitation can be reduced as a result of a volume discount by up to 25% for an increment of 25 units, this amount is increased to approximately $12,700 over the life of a conventional unit and $10,750 over an air to air unit (See Figure 14.) based on a constant amount of BTUs.

Maintenance savings of $240.00 per year were estimated by

LIFE CYCLE COST COMPARISON

Single Unit Rehabilitation

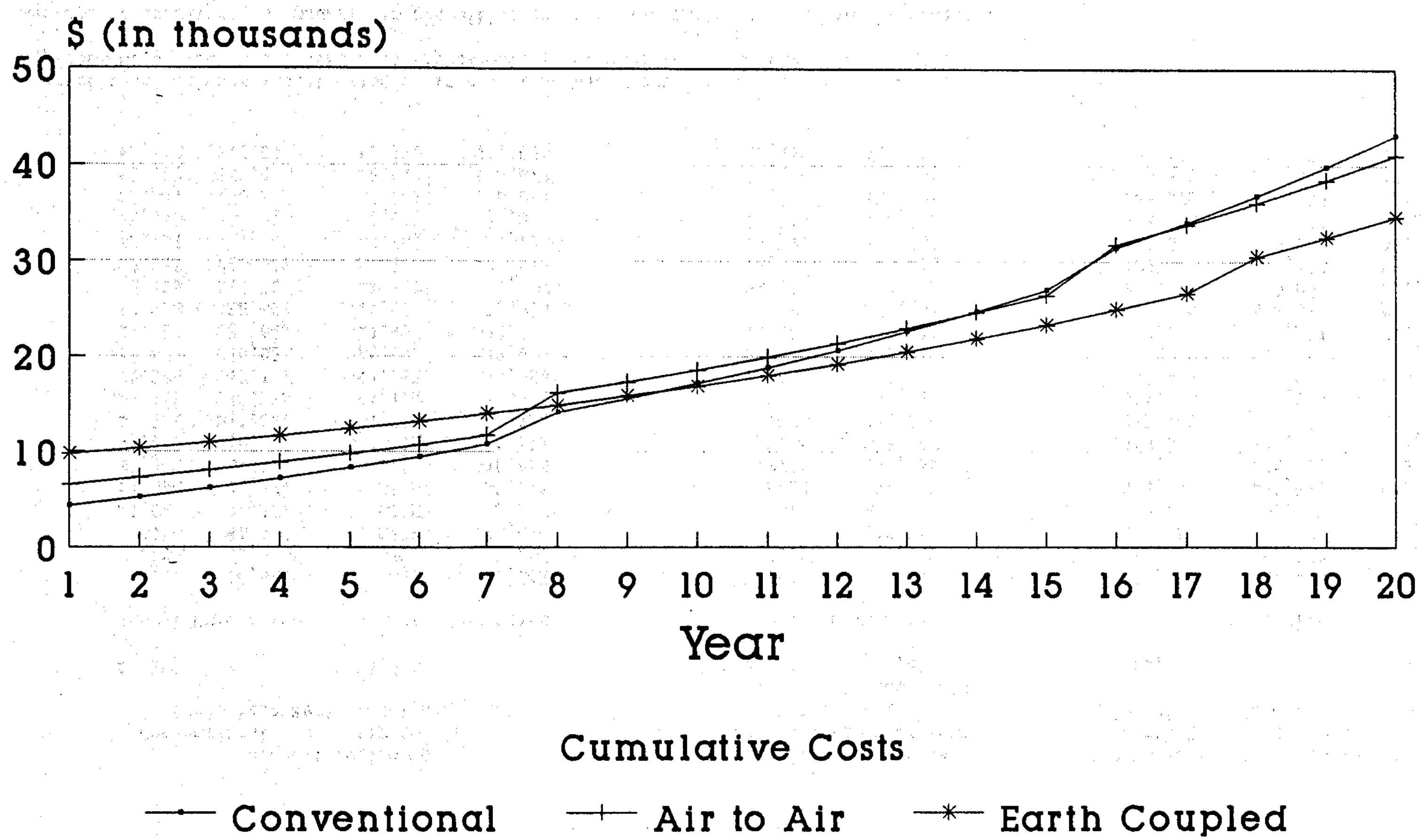


Figure 13

THE EARTH COUPLED HEAT PUMP

The Theoretical Model

	Rehabilitation Costs*** Conventional (8-10 Year Replacement Required)		Rehabilitation Costs*** Air to Air Pump (8-10 Year Replacement Required)		Rehabilitation Costs Earth-Coupled Heat Pump Single Unit (18 - 20 Year Replacement)*		Discounted Rehabilitation Costs Earth-Coupled Heat Pump 10 Units	Discounted Rehabilitation Costs Earth-Coupled Heat Pump 20 Units	Discounted Rehabilitation Costs Earth-Coupled Heat Pump 25 Units
Installation	$3,500		$5,906		Average**	$9,219	$8,297	$7,375	$6,914
Operational Costs	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Cumulative	Cumulative	Cumulative
Year 1	$822	$4,322	$656	$6,562	$540	$9,760	$8,838	$7,916	$7,455
Year 2	$884	$5,206	$705	$7,267	$581	$10,340	$9,419	$8,497	$8,036
Year 3	$950	$6,156	$758	$8,026	$624	$10,965	$10,043	$9,121	$8,660
Year 4	$1,021	$7,177	$815	$8,840	$671	$11,636	$10,714	$9,792	$9,331
Year 5	$1,098	$8,274	$876	$9,717	$722	$12,358	$11,436	$10,514	$10,053
Year 6	$1,180	$9,455	$942	$10,658	$776	$13,133	$12,212	$11,290	$10,829
Year 7	$1,269	$10,723	$1,012	$11,671	$834	$13,967	$13,045	$12,124	$11,663
Year 8	$1,364	$14,087	$1,088	$16,134	$896	$14,864	$13,942	$13,020	$12,559
Year 9	$1,466	$15,553	$1,170	$17,304	$964	$15,828	$14,906	$13,984	$13,523
Year 10	$1,576	$17,129	$1,258	$18,562	$1,036	$16,864	$15,942	$15,020	$14,559
Year 11	$1,694	$18,823	$1,352	$19,914	$1,114	$17,977	$17,055	$16,133	$15,672
Year 12	$1,821	$20,644	$1,453	$21,367	$1,197	$19,174	$18,252	$17,331	$16,870
Year 13	$1,958	$22,602	$1,562	$22,930	$1,287	$20,461	$19,539	$18,618	$18,157
Year 14	$2,105	$24,707	$1,680	$24,609	$1,384	$21,845	$20,923	$20,001	$19,540
Year 15	$2,263	$26,969	$1,806	$26,415	$1,487	$23,332	$22,410	$21,488	$21,027
Year 16	$2,432	$31,401	$1,941	$31,731	$1,599	$24,931	$24,009	$23,087	$22,626
Year 17	$2,615	$34,016	$2,087	$33,818	$1,719	$26,650	$25,728	$24,806	$24,345
Year 18	$2,811	$36,827	$2,243	$36,061	$1,848	$30,497	$27,575	$26,654	$26,193
Year 19	$3,022	$39,848	$2,411	$38,472	$1,986	$32,484	$29,562	$28,640	$28,179
Year 20	$3,248	$43,096	$2,592	$41,064	$2,135	$34,619	$31,697	$30,775	$30,314

* Initial cost includes installation of loop system which does not require replacement. Replacement of mechanical system is approximately the same as for a conventional unit.

** Average of actual costs incurred in rehabilitating the five units included in the project.

*** Initial rehabilitation costs average 40% - 75% more than new construction. All rehabilitation assumed to be 75% of new construction.

NOTE: Replacement calculated for 8th and 16th year for conventional and air-to-air units. Costs are calculated at rates adopted in 1987. An annual increase of 7.5% is assumed for each future year.

Table 3.

LIFE CYCLE COST COMPARISON

Multiple Unit Rehabilitation

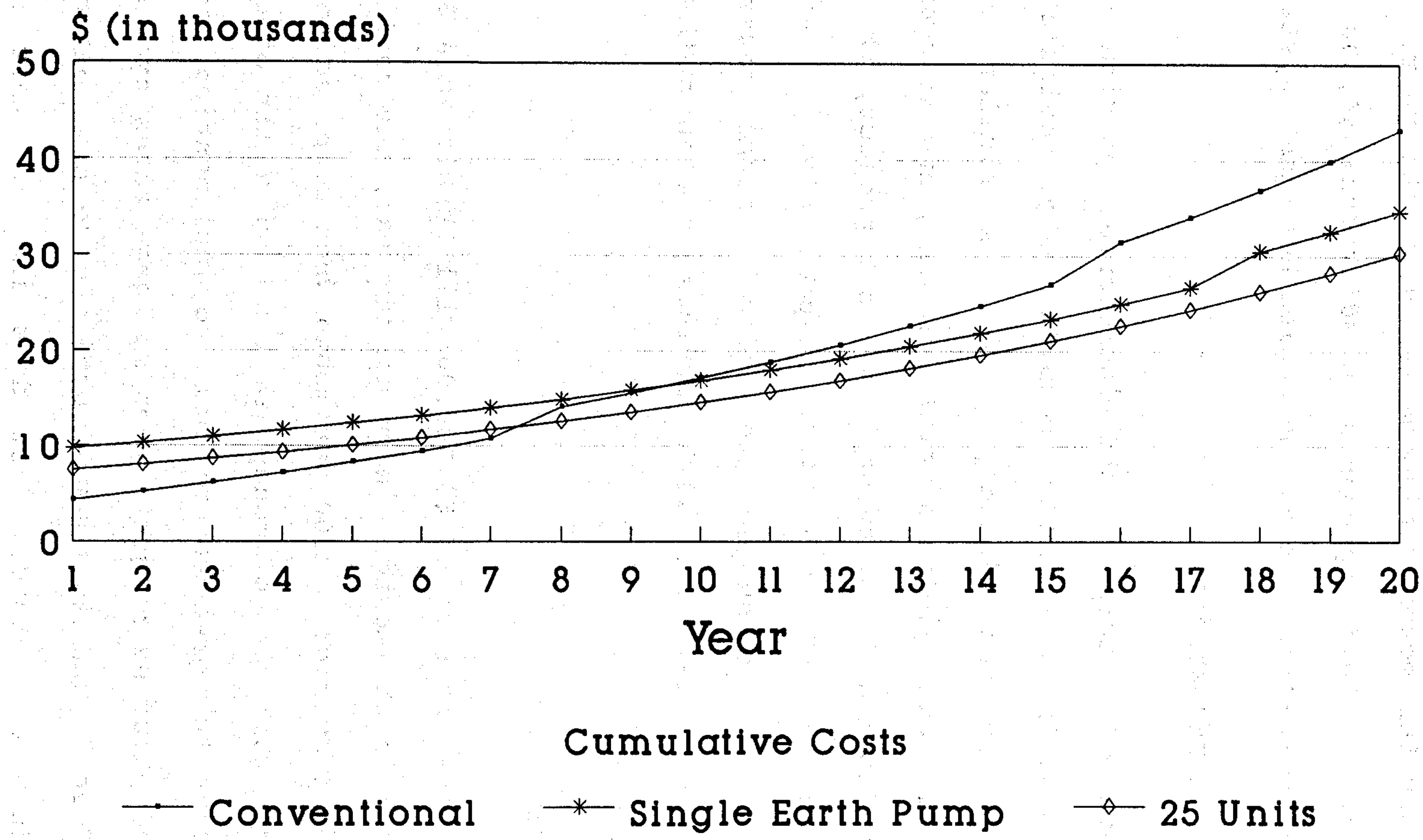


Figure 14

local Houston air conditioning contractors. These are typical costs associated with semi-annual condenser coil cleanings and condenser fan motor replacements every 4th year. Over a twenty year period, this represents an additional $4,800 in savings for the rate-payer with an earth-coupled heat pump system.

RETURN ON INVESTMENT

The rate of return on the incremental portion of the initial investment in the earth coupled pump, calculated at simple interest, is approximately 4.3%. A similar comparison with air-to-air pump yields a return of 6.3%, and if economies of scale can be assumed for a twenty-five unit project, the rate of return increases to 8.5% and 14.7% respectively. Inasmuch as these savings are not subject to federal income taxes, the savings compare very favorably with earnings from an ordinary certificate of deposit.

CASH FLOW

A mortgage increase of $3,300.00 will result in a $28.00 per month increase in the mortgage payment, whereas, the savings predicted by the model average $22.00 per month when compared to a conventional system. This cost of money, in addition to the other system costs, may prove the greatest obstacle to implementing the technology in low cost housing projects when mortgage rates exceed 8%. This can be offset in public housing projects to some extent, but only by some form of subsidy. It does indicate that public agencies providing low cost housing on a rental basis may prove a better vehicle for effecting a strong energy conservation program, until such time as the capital costs of initial installation can be reduced through volume discounting.

TAX CREDITS

Another factor which may provide some relief are tax credits against personal income taxes. The limitations of the tax credit in the context of low and moderate income families is the relatively low rate of taxes paid, although the credit does provide substantially more relief than the deductions of earlier years. The intent of Congress is clearly expressed in the Congressional Record where in its report on the Energy Tax Act of 1978 (Public Law 950618), the Senate Finance Committee stated that the purposes of the legislation were to "...induce consumers of oil and gas to conserve energy and convert to alternative energy sources". To meet this goal, the Energy Tax Act provided major tax incentives for the production of energy from such resources as geothermal, solar, wind, and biomass. These incentives-mostly in the form of tax credits, deductions, and allowances-have generated unprecedented interest in developing alternative energy projects.

However, regulations issued in 1981 by the I.R.S. have drastically limited the application of the alternative energy incentives enacted in 1978 and reaffirmed and expanded by the Crude Oil Windfall Profits Tax Act of 1980 (Public Law 96-223). With regard to geothermal energy, four specific limitations imposed by the I.R.S. appear to run contrary to Congressional intent since only water of a temperature of 122^{o}F or greater is considered "geothermal energy", even though the Energy Tax Act itself contains no temperature threshold. As a result, home owners or businesses with water cooler than 122°F cannot qualify for the residential or business energy investment credits.

A home owner who installs an earth coupled heat pump system to heat his residence cannot qualify for the residential energy credit unless 100 percent of the energy in the system is supplied by geothermal sources. Geothermal energy systems often include peaking equipment fueled by oil, gas, or coal. This peaking equipment typically provides less than 20 percent of the total annual energy load, since it is only used on the coldest days of the year. But, such peaking equipment would disqualify the system.

A business that installs geothermal equipment cannot qualify for the energy investment credit if the geothermal fluids are mixed with energy from another source. Geothermal resources may not, in some instances, be hot enough to fully satisfy an industrial process heat requirements. However, by adding a few degrees to the heat supplied from the geothermal source, it will often be possible to displace a large fraction of the conventional fuel consumed in the plant. Under the I.R.S. limitation, if a geothermal system requires even a minimal addition of non-geothermal heat, then the entire system becomes ineligible for the energy tax credit.

A company building an electric power plant using geothermal and energy from another alternative energy resource, such as biomass, can take the geothermal credit on the equipment run solely on geothermal energy and the biomass credit on the equipment fueled exclusively by wood. But, those components of the plant using both geothermal and biomass energy cannot qualify for either credit.

Therefore, the residential credit of 40% of the first $10,000.00 of qualifying expenditures for devices using renewable energy is not allowable in the case of earth coupled heat pumps. Bills have been introduced in both the House of Representatives and the Senate for the last two years but none have made it out of committee for a final vote. Apparently the current budget deficient limits legislative enthusiasm for providing relief to the nation's home owners faced with enormous utility bills.

UTILITY COMPANY REBATES

Oil prices have dropped significantly in the past few years, yet utility rates continue to climb. In response to projected growth rates in Texas, the utilities build new and larger power plants. The only viable alternative for the utility company is to encourage home owners to conserve energy. Furthermore, the electric utility company has the additional problem of having to provide plants capable of handling peak summer loads which then have far too great a capacity in the winter months. Thus they would like to flatten their load requirement by having more customers use electricity to heat their homes in the winter in lieu of natural gas. To encourage conservation most utility companies are offering rebates to either new or existing home owners who install high efficiency heat pumps. These rebates range from $200 per ton of cooling for units with an S.E.E.R. of 13 in Austin to $600 per unit for heat pumps with a 10 plus S.E.E.R. in Houston. Also, in Austin, the utility company provides another $100.00 rebate if a desuperheater is installed in the system. Since most geothermal heat pumps exceed 11 E.E.R. they more than qualify for these rebates. For example, a home owner in Houston could qualify for a $1,200.00 rebate by simply having two two-ton geothermal heat pumps installed in his home. This rebate would significantly offset the premium first cost of the ground loop system.

CONCLUSION

The size of the study precludes any conclusive finding that the incorporation of earth coupled heat pumps together with the more traditional conservation techniques of increased insulation and heat reflective attic foil is effective under all circumstances in defining single-family detached housing rehabilitation strategies.

The study has proven, however, that the technology has the potential for significant energy savings and actual dollar savings for individual home owners. The greatest problem appears to lie in the cost of money to actually finance the installation. Several solutions suggest themselves, many of which are most appropriate to public housing strategies: given the present cost of energy in the Gulf Coast region, tax credits and utility rebate programs appear to offer the most workable alternatives currently available. An assessment of other types of housing programs to which the technology could be beneficially applied may identify alternatives which were not considered in this assessment. Implementation of strategies to include earth coupled heat pumps in multi-family units would appear to have the potential to provide a greater return for the amount of capital invested, an area of investigation which this study does not support to address.

CHAPTER 5 - LESSONS AND APPLICATION

LESSONS LEARNED

The earth coupled heat pump is a viable energy conservation tool: the greater the dollar cost per BTU, the greater the opportunities. Financing the initial installation presents the greatest hurdle to large scale implementation in single family rehabilitation strategies at this time. Our study would indicate that although for the purposes of conducting the study the Urban Homesteading Program was a proper vehicle, it may not be the best mechanism for implementation of a large scale project. Because of the small size of the project, control of the variables and actual construction were overriding concerns in the selection of Urban Homesteading. A large scale implementation effort would necessarily sacrifice some elements of the controlled environment, but with the benefit of using a larger sample. Public housing, both single family scatter site and multi-family units and private rental projects may present greater opportunities for maximizing conservation for a lower initial capital investment - the former because of the relative freedom from market based mortgage financing, and the latter because of the opportunities for private investors to take advantage of depreciation allowances for federal income tax purposes.

Internally inconsistent federal energy policies coupled with the market phenomenon of a decrease in demand has the effect of increasing unit prices for the user, and discouraging aggressive risk-taking by both large agencies and individual consumers. This effect can be minimized with the active participation of local utilities, if and when they are prepared to reward individuals and other users for reducing peak load demands through innovative energy conservation techniques. The earth coupled heat pump would appear to be a technology well-suited to such a cooperative approach.

Although the project size was too small to ensure reliable results, the study provided insights which should prove valuable in conducting further study. It also underscored the difficulty experienced by public agencies in incorporating innovative and experimental approaches in practical applications, no matter how sound the approach or valid the concept.

Large organizations are very resistant to change: acceptance of the technology and the solution must be sought and established at every level. Change occurs very slowly, delaying project implementation often for a period of years. Any turnover in key personnel usually means that the project must be reinitiated and a new consensus formed. Often the innovative project becomes a casualty of administrative processes, notwithstanding its intrinsic merit, or the opportunities which it may represent for long term improvements in the system.

Reducing the energy consumed for the production of domestic hot water was not a part of this study. In the final analysis, it should have been included as part of an integrated conservation approach, in spite of the limited scope of the study and the small number of units tested. The observations of the project staff indicate that additional study of the earth pump which includes an element addressed to conserving energy required for hot water production should be undertaken.

SUGGESTIONS FOR APPLICATION

This analysis relies on empirical energy consumption data measured in British Thermal Units (BTUs). The costing of system installation, operation, and maintenance which forms the most fundamental part of the feasibility analysis can be adapted to fit conditions and rates applicable in other geographic areas within the temperate and sub-tropical coastal zones of the United States. Climatological conditions along the Gulf Coast of the United States would yield almost identical results, and it is anticipated that even more energy savings would be realized in areas which experience a narrower range of ambient outdoor temperatures and lower humidity. The methodology, if not the actual data collected, would be applicable in most other areas of the United States where the technology could be adapted to local conditions.

The analysis is perhaps most valuable as a starting point for an additional and larger study of the applications, the financing, and the housing programs into which such technology could be incorporated. It also provides very practical insights into the limitations of federal energy policies as they apply to providing incentives for the incorporation of innovative technology into single family housing rehabilitation strategies, as well as opportunities which should be assessed when considering guidelines for new housing in the future.

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APPENDIX A

Energy Consumption Data

THE EARTH COUPLED HEAT PUMP

The Theoretical Model

Conventional*	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total BTUs
All Electric	1,758,093	1,758,093	1,758,093	1,758,093	1,758,093	1,758,093	3,440,296	3,440,296	3,440,296	3,440,296	3,440,296	3,440,296	31,190,333
Gas Heat	3,542,328	3,542,328	3,542,328	3,542,328	3,542,328	3,542,328	3,617,370	3,617,370	3,617,370	3,617,370	3,617,370	3,617,370	42,958,190
Air to Air Pump*	708,296	708,296	708,296	708,296	708,296	708,296	3,440,296	3,440,296	3,440,296	3,440,296	3,440,296	3,440,296	24,891,556
Earth-Coupled Heat Pump	583,424	583,424	583,424	583,424	583,424	583,424	2,833,772	2,833,772	2,833,772	2,833,772	2,833,772	2,833,772	20,503,174

* SOURCE: Houston Lighting & Power based on the following assumptions:

- One story 1,600 sq. feet
- Occupied by a family of four
- Thermostat settings: 75 degrees for cooling
  70 degrees for heating

THE EARTH-COUPLED HEAT PUMP

Average Consumption in BTUs

Service Date	10/88	11/88	12/88	1/89	2/89	3/89	4/89	5/89	6/89	7/89	8/89	9/89	Total Consumption
Test	3,631,905	3,607,514	5,570,850	4,896,266	5,311,773	5,037,867	3,788,220	4,399,945	5,608,681	5,297,210	4,713,291	5,181,123	57,044,645
Control	4,224,657	3,449,035	7,670,474	9,678,300	9,260,905	9,408,400	5,379,114	4,773,720	5,771,652	5,941,279	5,339,579	5,476,376	76,373,491
% Difference	-14.03%	4.59%	-27.37%	-49.41%	-42.64%	-46.45%	-29.58%	-7.83%	-2.82%	-10.84%	-11.73%	-5.39%	-25.31%

Percentage Consumption Over/-UNDER for Test Units

	10/88	11/88	12/88	1/89	2/89	3/89	4/89	5/89	6/89	7/89	8/89	9/89	Total Consumption
Group 1	-40.57%	-1.33%	-37.70%	-38.10%	-41.03%	-40.65%	4.55%	38.46%	43.62%	24.51%	26.32%	22.86%	-12.32%
Group 2	36.08%	97.37%	19.55%	-30.66%	-22.78%	-37.29%	-4.34%	43.21%	29.40%	47.60%	41.35%	30.66%	9.02%
Group 3	-54.99%	-40.00%	-28.36%	-36.37%	-36.37%	-34.46%	-30.88%	-37.55%	-42.17%	-46.20%	-33.92%	-37.49%	-38.04%
Group 4	8.83%	-5.79%	-52.57%	-60.90%	-49.35%	-38.04%	-30.40%	-29.71%	-9.02%	-38.67%	-53.04%	-14.18%	-38.01%
Group 5	-19.61%	-0.55%	-17.88%	-70.10%	-62.99%	-71.32%	-65.22%	-45.35%	-8.26%	-12.90%	-7.92%	-20.45%	-45.92%

THE EARTH-COUPLED HEAT PUMP

Energy Consumption

Facility	Service Date	10/88	11/88	12/88	1/89	2/89	3/89	4/89	5/89	6/89	7/89	8/89	9/89	Total Consumption
#1 9247 Laura Koppe **	elec(kwh)	630	740	1,190	910	1,150	920	690	900	1,350	1,270	1,200	1,290	12,240
1,341 ft2	gas(ccf)	0	0	0	0	0	0	0	0	0	0	0	0	0
#2 9806 Kerry Glen *	elec(kwh)	1,060	750	1,910	1,470	1,950	1,550	660	650	940	1,020	950	1,050	13,960
1,419 ft2	gas(ccf)	0	0	0	0	0	0	0	0	0	0	0	0	0
#3 9727 Courben **	elec(kwh)	1,753	1,153	1,232	1,052	1,102	1,085	819	1,416	1,677	1,710	1,677	1,725	16,401
1,040 ft2	gas(ccf)	16	24	36	42	36	42	40	44	28	36	24	28	396
#4 9731 Courben *	elec(kwh)	919	589	672	569	541	553	549	890	1,285	1,291	1,216	1,303	10,377
936 ft2	gas(ccf)	24	12	42	92	76	106	52	34	22	20	16	22	518
#5 9038 Laura Koppe **	elec(kwh)	844	924	1,907	1,489	1,671	1,529	976	1,036	1,274	1,203	1,237	1,302	15,392
1,620 ft2	gas(ccf)	0	0	0	0	0	0	0	0	0	0	0	0	0
#6 9831 Kerry Glen *	elec(kwh)	1,875	1,540	2,662	2,340	2,626	2,333	1,412	1,659	2,203	2,236	1,872	2,083	24,841
1,600 ft2	gas(ccf)	0	0	0	0	0	0	0	0	0	0	0	0	0
#7 9815 Kerry Glen **	elec(kwh)	1,208	1,041	1,551	1,501	1,828	1,515	1,145	1,133	1,816	1,437	1,013	1,404	16,592
1,598 ft2	gas(ccf)	0	0	0	0	0	0	0	0	0	0	0	0	0
#8 9843 Kerry Glen *	elec(kwh)	1,110	1,105	3,270	3,839	3,609	2,445	1,645	1,612	1,996	2,343	2,157	1,636	26,767
1,600 ft2	gas(ccf)	0	0	0	0	0	0	0	0	0	0	0	0	0
#9 9109 Laura Koppe **	elec(kwh)	400	700	1,070	950	880	1,000	710	630	1,190	1,050	1,050	960	10,590
1,320 ft2	gas(ccf)	0	0	4	0	2	2	0	0	2	0	0	2	12
#10 9105 Laura Koppe *	elec(kwh)	15	161	364	282	309	319	292	429	820	723	718	800	5,232
1,351 ft2	gas(ccf)	16	18	36	96	74	112	58	24	18	16	14	16	498

* Control Group
** Test Group

THE EARTH-COUPLED HEAT PUMP

Conversion to British Thermal Units (BTUs)

	Service Date	10/88	11/88	12/88	1/89	2/89	3/89	4/89	5/89	6/89	7/89	8/89	9/89	Total Consumption
#1	9247 Laura Koppe ** 1,341	2,151,450	2,527,100	4,063,850	3,107,650	3,927,250	3,141,800	2,356,350	3,073,500	4,610,250	4,337,050	4,098,000	4,405,350	41,799,600
#2	9806 Kerry Glen ● 1,419	3,619,900	2,561,250	6,522,650	5,020,050	6,659,250	5,293,250	2,253,900	2,219,750	3,210,100	3,483,300	3,244,250	3,585,750	47,673,400
#3	9727 Courben ** 1,040	7,634,495	6,409,495	7,915,280	7,918,580	7,471,330	8,031,275	6,916,885	9,367,640	8,610,955	9,547,650	8,198,955	8,774,875	96,797,415
#4	9731 Courben * 936	5,610,385	3,247,435	6,620,880	11,419,135	9,675,515	12,806,495	7,230,835	6,541,350	6,654,275	6,468,765	5,800,640	6,715,745	88,791,455
#5	9038 Laura Koppe ** 1,620	2,882,260	3,155,460	6,512,405	5,084,935	5,706,465	5,221,535	3,333,040	3,537,940	4,350,710	4,108,245	4,224,355	4,446,330	52,563,680
#6	9831 Kerry Glen ● 1,600	6,403,125	5,259,100	9,090,730	7,991,100	8,967,790	7,967,195	4,821,980	5,665,485	7,523,245	7,635,940	6,392,880	7,113,445	84,832,015
#7	9815 Kerry Glen ** 1,598	4,125,320	3,555,015	5,296,665	5,125,915	6,242,620	5,173,725	3,910,175	3,869,195	6,201,640	4,907,355	3,459,395	4,794,660	56,661,680
#8	9843 Kerry Glen * 1,600	3,790,650	3,773,575	11,167,050	13,110,185	12,324,735	8,349,675	5,617,675	5,504,980	6,816,340	8,001,345	7,366,155	5,586,940	91,409,305
#9	9109 Laura Koppe ** 1,320	1,366,000	2,390,500	4,066,050	3,244,250	3,211,200	3,621,000	2,424,650	2,151,450	4,269,850	3,585,750	3,585,750	3,484,400	37,400,850
#10	9105 Laura Koppe * 1,351	1,699,225	2,403,815	4,951,060	10,851,030	8,677,235	12,625,385	6,971,180	3,937,035	4,654,300	4,117,045	3,893,970	4,380,000	69,161,280

APPENDIX B

Heat Pump Specifications

SECTION I - ADMINISTRATIVE PROVISIONS

Part 1 General

1.01 Requirements

A. Earth-coupled heat pump system installation. Fixed price contract.

1.02 Work Covered By Contract Documents

A. Work of this contract comprises complete general construction of the earth-coupled heat pump systems located at the sites identified in site specifications.

1.03 Contract Method

A. Construct the work under a single lump sum fixed price contrac

B. Contractor shall accept responsibility for the furnishing all tools, materials, and labor necessary for the complete installation of the earth-coupled heat pump and all other heating, cooling, and domestic water heating system components (forced air system; domestic water tank; thermostats; controls; connection of power; earth loops; connection of earth loop and water tank to the heat pump; supplemental/emergency resistance coils; etc.).

C. The Contractor shall complete all work within ______calender days after receipt of a purchase order.

D. All work shall be performed and completed in a thorough workmanlike manner and in accordance with the latest proven practices of the Manual Of Acceptable Practices For Installation Of Residential Earth-Coupled Heat Pump Systems approved by by the Energy Research And Development Authority.

E. A minimum of one year's warranty on materials and labor shall be provided. The warranty period shall begin the date the City officially accepts the complete system.

F. Acceptance and payment are to be conditioned upon completing the job to the satisfaction of the Department of Public Works and in accordance wiyh all conditions and requirements as detailed herein.

G. It will be the responsibility of the Contractor to inspect the sites prior to bidding and become familiar with the existing cinditions. No additional funds will be provided for conditions that the Contractor is unaware of. Any questions concerning the existing condition or specfications should be directed to ______________________________.

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H. It shall be the responsibility of the Contractor to obtain all building permits and pay all fees for the permits in accordance with the City of Houston building codes.

1.04 Coordination

A. Coordinate work of the various Sections of Specifications to assur efficient and orderly sequence of installation of construction element

B. Contractor must submit a schedule and site plan prior to start of job.

1.05 As-Built Drawing

A. Detailed, accurately dimensioned, as-built diagrams of the open loo shall be provided. The location of all fused connections shall provided.

SECTION II - VERTICAL BORE DRILLING

Part 1 General

1.01 Work Included

A. Drilling of vertical base holes for the installation of a vertical earth loop system.

B. Backfill.

C. Granular materials as required.

D. Restoration of surfaces.

1.02 Submittals

A. Submit material reports and cut sheets on all material used in the work.

Part 2 Materials

2.01 Granular materials

A. Sand shall be used to bed piping and backfill bore holes after installation of vertical earth loops.

B. A combination of sand and pea gravel may be substituted for backfill of bore holes after installation of vertical earth loops.

Part 3

3.01 Protection

A. Protect sidewalks, paving, and curbs from equipment and vehicular traffic.

B. Protect above and below grade utilities which are to remain.

C. Protect bottom of excavations and soil adjacent to and beneath foundations from frost.

D. Protect surrounding structures from air pressure or water pressure related damage.

3.02 Preparation

A. Comply with local ordinances before excavating. Contact UFPO (Underground Facility Protection Organization) to locate existing buried services and obstructions.

3.03 Excavation

A. Vertical earth loop size, configuration, bore depth, pipe diameter minimum bore spacing, and layout shall be as in site specifications.

B. The site specifications list the required length of vertical bore an assumed bore depth and number of bores. The installed length vertical bore is critical, the number of holes and depth is not, long as they are 80 ft. deep or more. The contractor may use judgeme based on actual site drilling conditions as to how many holes a required at what depth.

SECTION III - BITUMINOUS MEMBRANE WATERPROOFING

<u>Part 1 General</u>

1.01 Work Included

A. Cold-applied asphalt bitumen waterproofing on foundation wall.

1.02 Submittals

A. Catalog cuts shall be supplied for all materials used.

1.03 System Description

A. Waterproofing system: Prevent moisture migration to interior.

<u>Part 2 Product</u>

2.01 Materials

A. Use a non-hardening material to provide for expansion and contraction.

<u>Part 3 Execution</u>

3.01 Moisture Protection

A. Mortar the sleeves into the foundation wall from both the inside and outside using a hydraulic Mortar, following manufacturer instructions for application and curing.

B. Insert earth loop pipes through the sleeves and caulk the pipe sleeve space with non-hardening damp-proofing material from both the inside and outside, following manufacturer instructions for application and curing.

C. Apply non-hardening damp-proofing material to the earth loop pipe/sleeve/wall area, following manufacturer instructions for application and curing.

SECTION IV - EARTH LOOP PIPE AND FITTINGS

Part 1 General

1.01 Work Included

A. Earth loop pipe, fittings and connections.

1.02 Submittals

A. Catalog cuts shall be supplied for all materials used.

Part 2 Products

2.01 Pipe

A. Pipe shall be schedule 40 polyethylene or polybutylene.

2.02 Joints And Fittings

A. All underground connections shall be thermally fused.

B. Polyethylene pipe, elbows, end caps, service saddles, U-bends ar plastic-to-threaded metal adapters shall be butt fused.

C. Polybutylene pipe, couplings, tees, elbows, end caps, U-bends, ar plastic-to-threaded metal adapters shall be socket fused.

Part 3 Execution

3.01 Joints

A. Polyethylene and polybutylene pipe shall be fused with equipmer recommended by the manufacturer.

B. Fused joints shall be straight and true.

3.02 Installation

A. All piping shall be carefully installed to proper lines and shall b connected as described above.

B. Piping shall be snaked in the trench to compensate for expansion ar contraction.

C. All pipe and joints shall be pressure tested prior to backfilling.

D. All parallel paths shall be flow tested prior to backfilling.

SECTION V - AUXILIARY EQUIPMENT

Part 1 General

1.01 Work Included

A. Loop pump(s).

B. Domestic hot water recirculation pump.

C. Water storage tank(s).

1.02 Submittals

A. Catalog cuts shall be supplied for all equipment used.

Part 2 Products

2.01 Loop Pumps

A. Pumps shall be centrifugal pumps suitable for the particular antifreeze, and temperatures of 20 degrees F to 100 degrees F.

B. Pumps shall be suitable for 115VAC or 230VAC power.

2.01 Domestic Hot Water Recirculating Pump

A. Pumps shall be centrifugal pumps suitable for water with a maximum of 190 degrees F temperature.

B. Pumps shall be suitable for 115VAC to 230VAC power.

2.03 Water Storage Tanks

A. Storage tanks shall have sufficient capacity to store 2 hours of heat.

B. Storage tanks shall be insulated tanks of the water heater type and have an R rating equal to or greater than 8.00.

C. Tanks shall be glass lined and galvanized for corrosion protection.

Part 3 Execution

3.01 Installation

A. Pumps shall be mounted on the piping with mounting brackets supplied by the pump manufacturer.

B. Pumps shall be mounted in such a manner so as not to cause vibration.

SECTION VI - INSULATION

Part 1 General

1.01 Work Included

A. Piping insulation

B. Duct insulation

1.02 Submittals

A. Catalog cuts shall be supplied for all materials used.

Part 2 Products

2.01 Pipe Insulation

A. Insulation shall be foam with a minimum thickness of one (1) inch.

B. Insulation shall have a mimimum R rating of 8.00.

2.02 Duct Insulation

A. Insulation shall be duct board with flexible insulated runs.

B. Metal duct shall be wrapped with one (1) inch insulation with a minim R rating of 8.00, or lined with same.

Part 3 Execution

3.01 Insulation

A. Insulation shall be installed tight to piping and duct work.

B. Insulation shall be installed in accordance with manufacturer` instructions.

C. Insulation shall be located in the least visible locations.

D. Insulation shall be finished neat at all pipe and duct supports an changes in directions.

E. Insulate all fittings except valves, visual flow meters etc. require access or clearance to properly function. At these locations, insula areas that need not be exposed, and neatly bevel and seal ends insulation.

SECTION VII - PLUMBING PIPING

Part 1 General

1.01 Work Included

A. Indoor earth loop piping.

B. Recirculation loop piping (desuperheater to pre-heat tank).

C. Antifreeze solution.

1.02 Submittals

A. Catalog cut sheets shall be supplied on all materials used in the work.

Part 2 Products

2.01 Design

A. Piping shall be sized to provide a flow equal to 3 gpm/ton with the pumps selected for the system.

2.02 Materials

A. Indoor earth loop piping shall be copper (if antifreeze compatible) or the same material as the earth loop.

B. Recirculation loop piping shall be copper or high temperature (grey) polybutylene.

C. Hangers for piping shall be manufactured by a nationally known company. Piping supports shall be provided at intervals of ten (10) feet or less or at changes in direction.

2.03 Glycol Solution

A. Provide antifreeze solution suitable for a low temperature of 15 degrees F.

B. Utilize antifreeze recommended by the manufacturer.

Part 3 Execution

3.01 Installation

A. Piping shall be run level and true.

B. Piping shall be pressure and flow tested prior to installation of insulation.

C. Recirculation loop piping shall be sized such that the flow recommended by the manufacturer is obtained with the use of the selected recirculation pump.

D. Standard pump kits shall be utilized for both the earth loop and domestic hot water circuits.

3.02 Antifreeze Solution

A. Purge air out of the earth loop following the heat pump manufacturer' recommendations.

B. Thoroughly clean and flush system before adding antifreeze solution.

C. Feed antifreeze to system displacing an equal amount of water b volume, and run th earth loop pump to thoroughly mix the solution.

D. Perform tests to verify the 15 degrees F freeze point.

SECTION VIII - EARTH-COUPLED HEAT PUMP

Part 1 General

1.01 Work Included

A. Provide and install earth-coupled heat pumps.

1.02 Submittals

A. Submit materials, reports, and cut sheets on all equipment used in the work.

Part 2 Products

2.01 Heat Pump

A. The heat pump supplier must have data for 25 degrees and 90 degrees F entering liquid temperature (ELT), and be operable throughout that ELT range.

B. The heat pump supplied must be a packaged liquid-to-air unit with parasitic (partial) or demand (total) desuperheater for domestic hot water provided as an option.

C. The heat pump must have provision for condensate collection off of the evaporator in the cooling mode, with appropriate disposal.

D. The heat pump must have provision for condensate prevention, and/or collection and disposal, off of the freon-to-liquid heat exchanger and other internal components in the heating mode.

E. The heat pump supplier must provide with each unit, suitable installation, operation and maintenance manuals specifically designed for the earth-coupled heat pump application.

F. The heat pump size, CFM, GPM, and backup/emergency heat type and size shall be as in the site specifications.

Part 3 Execution

3.01 Installation

A. Heat pumps shall be installed in strict accordance with manufacturers recommendations.

B. All piping shall be mounted so as not to impose undue stress on the heat pump.

C. Flexible connections shall be used for connecting all duct work to heat pumps.

D. Condensate drains shall be run from heat pumps to common drain for cooling heat pumps.

SECTION IX - MECHANICAL EQUIPMENT POWER AND CONTROLS

Part 1 General

1.01 Work Included

A. Earth-coupled heat pump system controls.

B. Earth-coupled heat pump system power.

Part 2 Products

2.01 Controls Equipment

A. The heat pump must be shipped from the factory with low temperatur protection consistent with source temperatures as low as 25 degrees (Field installation of factory approved components in compliance wi the warranty is acceptable).

B. The heat pump must be shipped from the factory with a time delay rela preventing compressor on-cycling prior to freon pressure equalizati after the previous cycle, or a hard-start kit comprised of a sta capacitator with potential relay (Field installation of factc approved components in compliance with the warranty is acceptable).

C. The heat pump must be installed with a 2 stage heating, 1 stag cooling thermostat with an emergency heat switch. First stage heati is the heat pump, second stage heating is the backup source (resistar coils), and first stage cooling is the heat pump. In the emerger heat mode, the backup energy source cycles on first stage and the he pump compressor is unused. All operational modes shall be verified time of installation.

2.02 Power

A. The backup/emergency heat shall be provided by electric resistanc coils, powered by a separate circuit.

B. The hot water backup and storage shall be provided by an electric wa heater, powered by a separate circuit.

Part 3 Execution

3.01 Installation

A. Install power wiring in accordance with manufacturer's instructions a in compliance with applicable electric codes.

B. The earth-coupled heat pump (compressor, blower, loop pump, recircula pump) shall be powered by one 4-conductor cable at 220V. T compressor and blower are internal to the packaged unit and are power directly. The loop pump and recirculator pump are powered from t packaged unit using one leg of the 220V (i.e., 110V).

C. Activation of the comprerssor lockout relay must also automatically place the system in emergency heat mode and activate the emergency heat indicator light on the thermostat. (Field installation of factory approved components in compliance with the warranty is acceptable).

REPORT AND INFORMATION SOURCES

Additional copies of this report *The Earth-Coupled Heat Pump: Utilizing Innovative Technology in Single Family Rehabilitation Strategies* are available from:

Publications and Distributions
Public Technology, Inc.
1301 Pennsylvania Avenue, NW
Washington, D.C. 20004

For additional information on the structure, operations and results included in this report, or for information on other energy management activities of the City of Houston, please contact:

Marina M. Sukup
Department of Planning & Development
Fourth Floor, City Hall Annex,
P. O. Box 1562
Houston, TX 77251
(713) 247-2558

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