iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** VIII **Month of publication:** August 2022

DOI: https://doi.org/10.22214/ijraset.2022.46476

Performance Assessment of Ground Source Heat Pumps to Offset Domestic Energy Consumption in Pakistan

Faisal Habib[1], Salman Saeed[1]
[1]National Institute of Urban Infrastructure Planning (NIUIP), University of Engineering and Technology Peshawar, Pakistan

Abstract: This paper presents an experimental based performance evaluation of ground source heat pumps (GSHP) to offset domestic energy consumption in Pakistan. Global population growth and rising energy consumption drove up demand for fossil fuels, adding to pollution and hastening the effects of climate change. A clean, renewable, durable, and cost-effective technology is GSHPs, which could help ease the burden of energy-intensive industries like residential cooling and heating. But due to the lack of performance characteristics of GSHP, resulting in less people opting for its installation and usage in homes. The performance assessment of GSHP system is carried out to provide financial sustainability of using this technology for heating and cooling in homes. It will also enable the readers to know the price range of this system and hence, better prepare them to take more informed decisions in the use of energy conservation and the quest for alternative/renewable energy means. The results show that by installing GSHP system, reduced excavation/backfilling, materials and other component ((like pump, radiator, water tank) costs that contributed 50%, 20% and 30% of the total costs of the system respectively. It is also noted that that GSHP system (1500ft of pipe length, placed at shallowest depth of 15ft) took 2.16 years while the system (placed at 15ft depth and having heat exchanger length of 1000ft) took 0.64 years to return its cost. If the GSHP system is insulated efficiently it can produce 3 to 4.5 time's electrical energy that can serve for heating multiple homes. Based on these results, it can be concluded that GSHP system can be considered a viable solution to offset domestic energy consumption in Pakistan.
Keywords: Ground Source Heat Pumps (GSHP), Cost Analysis, Cost of GSHP, Sustainability

I. INTRODUCTION

The drastic growth in the world population increases the energy demand and usage causing depletion of energy resources. The energy crisis increased the use of fossil fuels to meet the energy requirements is also hazardous to the environment and accelerates the climate change phenomena [1,2]. Given that Pakistan is currently experiencing a serious energy crisis as a result of the electricity shortage, the necessity for alternate and efficient energy producing methods is now obvious. The Government is making efforts to address this situation by 2025, but more effective air conditioning systems are required to keep up with the evolving energy landscape. Pakistan is one of the nations with some of the highest domestic energy consumption rates in the world. Pakistan uses roughly 45.9% of its total energy for domestic use each year, compared to about 27.5% for the industrial sector. The total energy used for HVAC applications is about 37% [3]. Therefore, it is clear from the facts that energy consumption is important to create a comfortable indoor environment for people. Utilizing efficient air-conditioning technology and increasing the effectiveness of the currently present systems can save expenses, energy use, and enable the creation of a healthy environment.

Buildings that provide comfortable air conditioning frequently use a lot of electricity. Separate cooling and heating systems are typically employed to keep the inside space within a comfortable temperature range, and these systems consume energy produced from energy sources like fossil fuels and other resources that are quickly running out. The earth, including its water resources, absorbs about 46% of solar energy in the form of radiation. It is necessary to investigate new, clean energy options and make efforts to meet the energy needs of relatively large sectors using ecologically friendly, renewable energy sources in order to get around the limitation. Residential cooling and heating requirements have a reputation for using a lot of energy. Ground source heat pumps can be used to cool and heat with this absorbed energy (GSHPs). The ground source heat pumps, which also include ground coupled heat pumps, surface water heat pumps (SWHPs), and ground water heat pumps (GHPs). Due to their superior cooling and heating capabilities compared to traditional air conditioning systems, these systems have grown in popularity. Additionally, these systems are environmentally safe and can provide large reductions in electricity consumption while still offering excellent levels of comfort both in cool and warm climates [4-6].

The GSHP is a heating and cooling system that utilizes the earth's essentially constant temperature for usage as an HVAC system in buildings. At that latitude, the earth's temperature is nearly constant between 2 and 6 meters below the surface and is roughly comparable to the planet's mean annual air temperature. [7]. It is less expensive to install GSHPs in newly constructed buildings than it is to retrofit an existing one. However, installing a GSHP in an existing home can pay for itself and cover the cost of moving away from a conventional HVAC system. To utilize the heat produced by the GSHP to its full potential, a house must be properly insulated.

The majority of the parts is maintenance-free and has lifespans of up to 20 years [8]. Unlike solar or wind energy sources that must be placed on roofs or walls, GSHPs are a discrete renewable energy source. In many situations, GSHP infrastructure sustains the building itself because of its extremely low maintenance needs, limited fire hazards, and reduced operating noise [9]. GSHPs are significantly more environmentally safe than conventional and traditional heating and cooling systems, have lower operating costs, and are up to four times more efficient. One of GSHPs' biggest advantages is their high efficiency makes GSHP systems more financially viable. Just because GSHPs only move heat from one location to another and don't burn fuel or produce energy are high COPs of up to 4.5 attainable. A COP of 4.5 indicates an efficiency of 450%, whereas the best oil-fueled furnaces can only be 100% efficient in terms of energy used to heat energy provided. Although GSHP systems are more expensive than conventional systems [10], the International Ground Source Heat Pump Association (IGSHPA) claims that GSHPs can reduce heating and cooling expenditures by between 25% and 50% when compared to conventional cooling and heating systems. A GSHP system can recoup the cost of its installation in 5 to 10 years by saving customers money on their energy bills. The ensuing cost reduction is therefore pure saving, according to the Department of Energy, USA, following the payback time of 5 to 10 years [11]. Ji Liang et al. (2011) conducted an investigation to assess the effectiveness of shallow water heat pump systems in China, contending that consistent water temperature in small lakes rather than deeper water can produce high performance outcomes [12]. To determine the energy potential in the source, Pengfei Si et al. (2015) provided an optimal methodology for river water temperature estimation for water source heat pump systems [13].

The aforementioned literature study demonstrates that although ground heat pump (GSHPs) technology is utilized throughout the world, little research has been done on how it is applied in Pakistan. Although some research has been done on Pakistan's geothermal potential, no technologically significant discoveries have been made [14, 15]. This study's is based on experimental assessment of ground heat pump systems (GSHPs) at Hayatabad, Peshawar Pakistan. There have been a few studies in Pakistan on the viability of GSHPs, but none have examined their cost-benefit ratio. As a result, this research will shed light on previously unexplored locations. Less people are choosing to install and use GSHP in their homes because they are unaware of the costs involved. The cooling and heating capabilities of the GSHP will be thoroughly analyzed, and the public will be informed of the financial advantages and encouraged to adopt the technology. It is necessary to have a basic understanding of the characteristics that might determine the cost of a GSHP system. These qualities include the type of ground loop, the complexity of the installation and any upgrades, the quality of the equipment and the site's conditions, as well as the cost of operation (electricity and water) and maintenance. The goal of this study is to determine the link between the quantity of heating or cooling that can be provided by the GSHP system and the temperature gradient provided by the system. Additionally, it will go over the costs analysis of various components and the effectiveness of using GSHP to heat and cool buildings in Hayatabad, Peshawar, will be examined about the usefulness, significance, and economic viability of GSHP systems in order to promote their wider usage. The purpose of the study is to compare the GSHP to the conventional HVAC system in terms of cost-benefit analysis.

II. METHODOLOGY AND EXPERIMENTAL PROGRAM

The excavation, subsequent laying of an HDPE pipe loop, and the installation of a full-fledged GSHP system took place at a site in Hayatabad Peshawar, Pakistan, which is part of the NIUIP campus. In the investigation, high density polyethylene (HDPE) pipes were used in the GSHP system. Excellent heat transmission capabilities, chemical inertness, cost-effectiveness, extended lifetime, and a number of other physical characteristics are all present in HDPE [16]. A further extensive manual, "A Guide for Installation of Ground Source Heat Pumps - A user Instruction Manual," is available and has detailed instructions for installing and laying pipes, sensors, and other equipment [17]. In order to lay the HDPE pipe loop for the horizontal ground source heat system, a space measuring 63 feet long by 47 feet wide had to be excavated. Using the excavator machine depicted in Figure 1, the area was dug to a depth of 15 feet. After placing the pipes in the excavation, tiny stones were used to make grooves in the ground that were later removed. The pipe system was examined for leaks before the ditch was sealed. To prevent damage from sharp objects and stones as well as to prevent voids from forming around the pipes and to maximize contact with the subsurface soil, sand was used for backfilling.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VIII Aug 2022- Available at www.ijraset.com

(a)

(b)

(c)

(d)

Fig. 1: Site Preparation of GSHP System Installation (a) Excavation (b) Pipe Laying (c) Backfilling (d) Leveling and Compaction

A total of 1500 feet, 1000ft and 500ft of 20 mm internal and 25 mm external HDPE pipe were laid in snail design at three depths of 5 feet, 10 feet, and 15 feet. The pipe was spaced 2 feet apart from one another to allow for soil heat dispersion [18-20]. The GSHP system's operation includes water collecting in a tank, water circulation via a pump, tracking of various consumptions, and cost analysis. The electrical energy used by the 0.5 HP pump and the heat energy gained/lost by running the pump were used to calculate the cost of operating the GSHP system to achieve a specific drop/rise in temperature. For clarification, the costs associated with operating the pump were compared to the costs associated with achieving the same energy loss/gain using a conventional HVAC system. Heat is a kind of energy transfer, therefore whenever an object receives or loses heat, the energy that it possesses changes. Usually, the change in temperature is used to gauge this energy change. Each substance has unique specific heat energy, which is the amount of heat needed to increase an object's temperature by one degree Celsius per unit mass. J/g/°C units are used to calculate an object's specific heat energy.

III. RESULTS AND DISCUSSION

A. Cost Analysis of GSHP System Installation

The excavation work for installing GSHP system were carried out by using backhoe excavator of volume 44,415 ft3 (Length = 63 ft, width = 47 ft and depth = 15ft). The total cost incurred in excavation and laying work of different specification of GSHP systems were presented in Table 1 as per per MRS-2020 Manual, Khyber Pakhtunkhwa, Pakistan. The analysis of result in Figure 2 shows that while increasing the length and depth of excavation/backfilling for the GSHP system significantly increase the cost of installation. It is evident that increasing the depth of the pipe loop has a greater impact on excavation costs than extending the length of pipe since excavation in the area's hard (rocky) soil is quite expensive. Excavation and backfilling expenses associated with this requirement account for about 50% of the GSHP system's overall expenditures. The details of pipe and lying cost of GSHP system is shown in Figure 3. The analysis of result in Figure 2 shows that while increasing the length of pipe and depth of excavation increases the cost of pipe including placement cost for the GSHP system. It is worth mentioning that the cost of pipe and placing expenses account for 20% of the total cost of the GSHP system installation.

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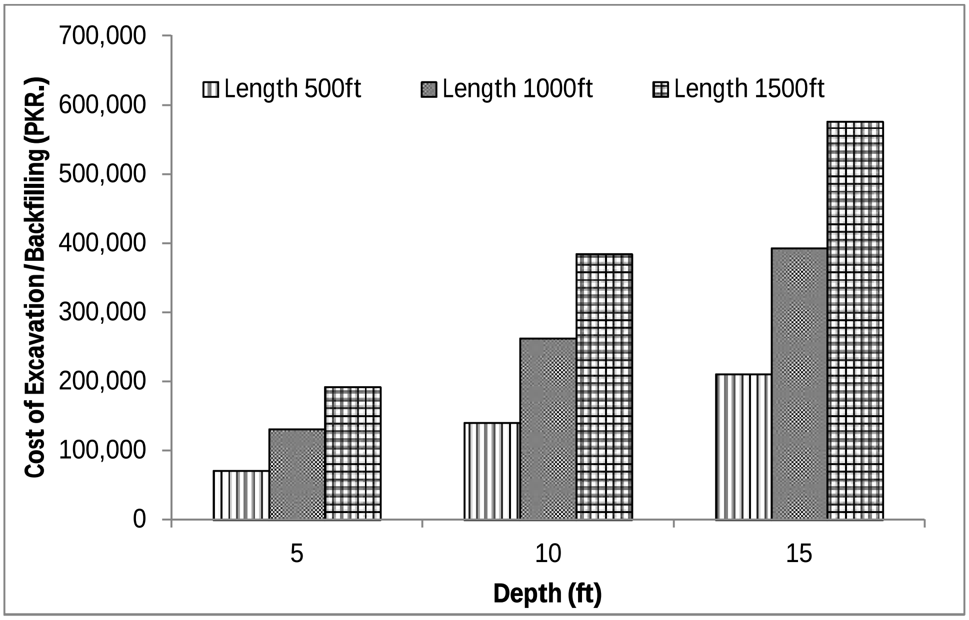

Figure 2: Cost of Excavation/Backfilling for Installation of GSHP System

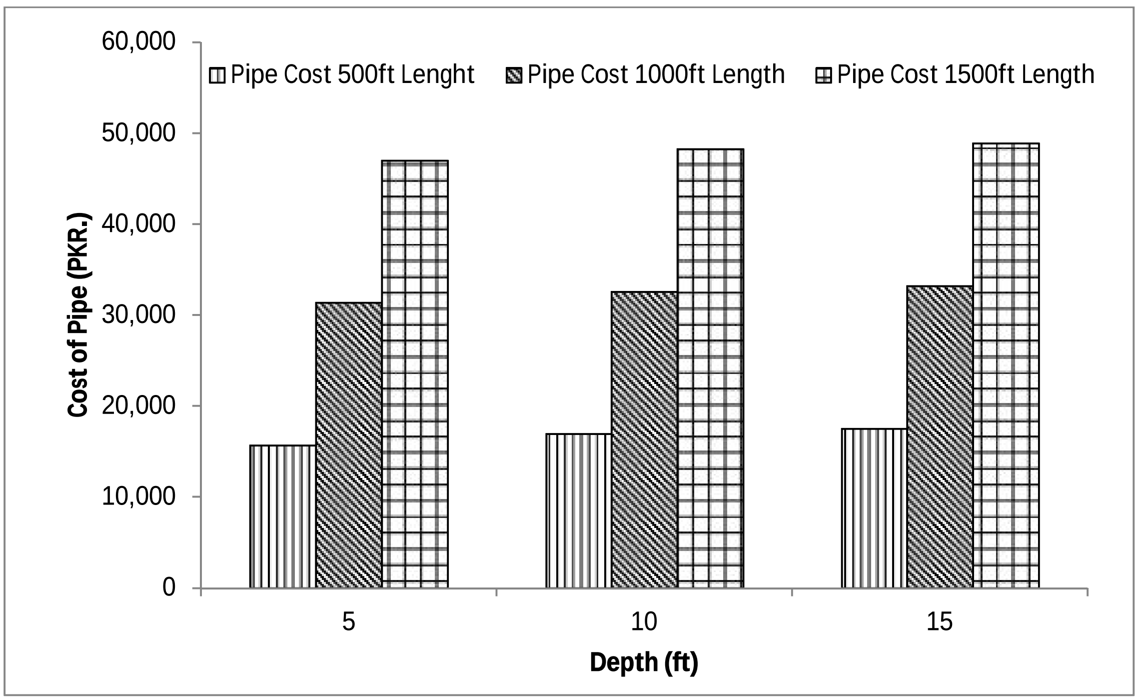

Figure 3: Cost of Pipe Including Placement

A water pump, a radiator, and a water tank are additional elements needed for the GSHP to operate successfully in order to distribute and regulate the heat input/output from the system's premises. The price of these parts raises the GSHP system's overall cost, which accounts for 30% of a system's total cost. Pump and water tank prices were respectively PKR 14,076 and PKR 21,072, and they were unaffected by the length and depth of the GSHP system pipes.

B. Sensitivity Analysis of Cost of GSHP System Installation

Figure 4 displays the sensitivity analysis of GSHP system installation costs. The outcome demonstrates that the cost of civil work, which consists of civil works like excavation and backfilling for GSHP system installation, is more sensitive. It is based on the cost breakdown.

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The cost of the civil work, which accounts for 70% of the system's overall cost, rises as the GSHP system pipe's depth and length do as well. By lowering the cost of civil work relative to the cost of pipes and other component costs, the cost of a GSHP system can be decreased.

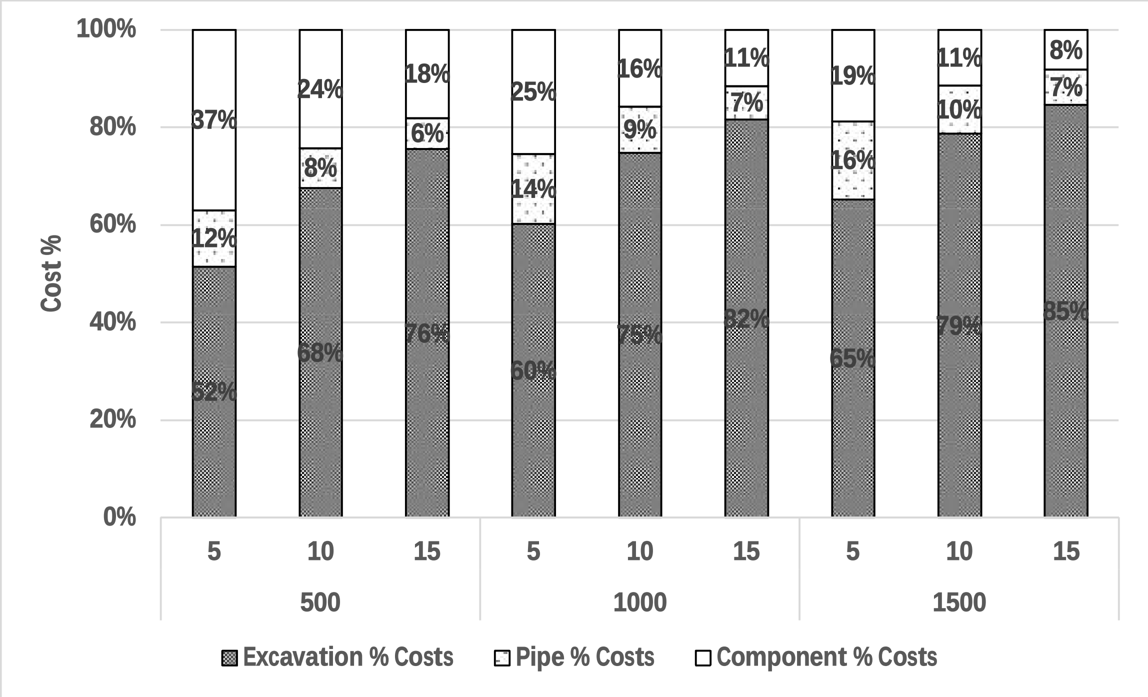

Figure 4: GSHP Installation Cost Sensitivity Analysis

C. Cost Analysis of GHSP System Operation

The annual electricity usage of GSHP and split air conditioners (AC) with comparable cooling capacity is shown in Figure 5. The consumption shown in Figure 5 is in accordance with the operational state shown in Table 1. Three years' worth of operating costs for each system were extrapolated (the longest time taken by the studied GSHP systems to return its initial costs). The outcome demonstrates that the operating expenses of the AC continue to rise significantly when compared to GSHP systems with equivalent cooling capacity. When compared to air conditioners that offer the same level of cooling efficiency, the GSHP system saves more than 50% of the cost. Additionally, the savings are considerably greater than the price of a single GSHP system. The conclusion that can be drawn from the results is that, in terms of annual electricity consumption, GSHP systems are more effective than air conditioning systems.

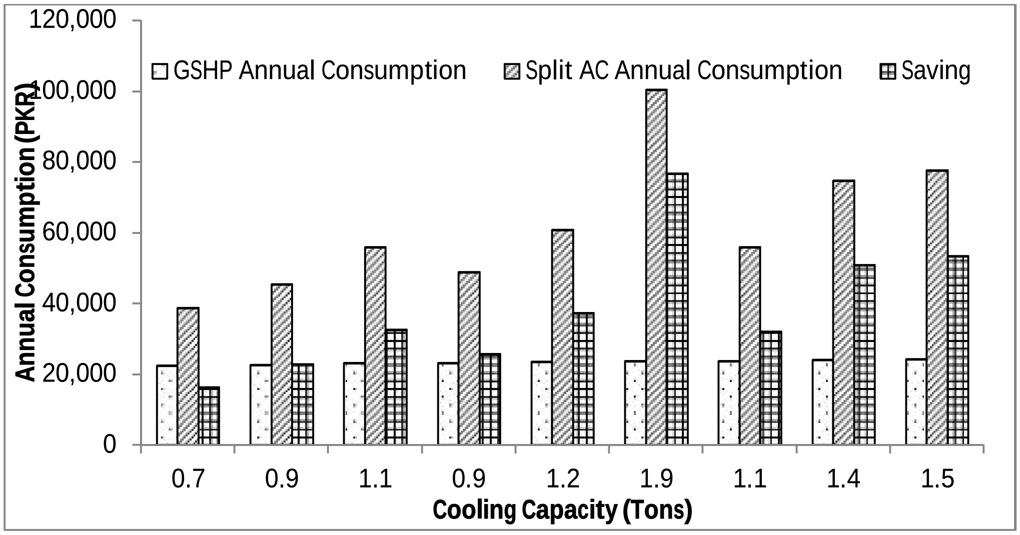

Figure 5: GSHP and AC System Annual Consumption Cost Analysis

Table 1: Annual Electricity consumption Factors of GSHP and Split AC System

Factor	Value	
	GSHP	Split AC
Thermostat Temperature	25℃	25℃
Running Duration	24 hrs.	24 hrs.
Pump Rating	0.5 HP	----
Electricity Unit Rate	15 Rs/KW-h	15 Rs/KW-h
No. of Days/year	200 days	200 days
Cooling Capacity	----	Tons
EER	----	10
Load Factor	----	60% (0.6)

D. Cost-Benefit and Break-Even Analysis of GSHP System

According to the experiment's findings, which are presented in Table 2, the payback and future value of money were determined i relation to the GSHP systems' break-even point. The State Bank of Pakistan's 2021 interest rate of 7.25% was used for the analysis's purposes. In comparison to all earlier GSHP system iterations, it was found that the 1500-foot-long pipe put at a depth of 15 feet required maximum time for cost recovery through energy savings. The data indicates that it would take this system about two years, one month, and twenty-eight days to achieve its return on investment. On the other hand, the GSHP system, which had a pipe length of 1000 feet and was installed at a depth of 15 feet, recovered its initial cost in just 7 months and 20 days. Therefore, the results are quite positive, and the system may lead to significant energy savings over the course of its lifetime. The GSHP system will also help protect the environment from pollution caused by the use of fossil fuels and other energy sources, which emits a variety of toxic gases.

Table 2: Cost-Benefit and Break-Even Analysis of GSHP System

Pipe L (ft.)	Pipe D (ft.)	Cooling Capacity (Tons)	Total Cost on GSHP (PKR)	Total Cost on AC (PKR)	Pay Back (Years)	FV of Money (PKR)
500	5	0.7	158298	103671	4.36	184357
	10	0.9	229897	121416	5.77	310315
	15	1.1	301136	135797	6.07	425149
1000	5	0.9	240714	124822	5.52	320178
	10	1.2	373248	139802	7.25	581148
	15	1.9	505155	220393	4.72	669640
1500	5	1.1	317862	135797	6.68	469431
	10	1.4	511332	157752	7.97	851195
	15	1.5	704173	161958	11.17	1486296

IV. CONCLUSIONS

According to the findings, implementing GSHP systems place at 15 ft having 1000 ft length lowered expenses associated with excavation/backfilling, materials, and other system components (such as pumps, radiators, and water tanks), which contributed 50%, 20%, and 30% of the system's overall expenditures, respectively. It should be noted that a GSHP system with 1500 feet of pipe installed at the shallowest depth of 15 feet required 2.16 years to pay for itself, whereas a system with a heat exchanger located at the same depth but with a length of 1000 feet required 0.64 years. The GSHP system may produce 3 to 4.5 times as much electrical energy, which can be utilized to heat several homes, if it is adequately insulated. It is also concluded that the system with the best normalized beginning cost, or best value per tonnage, was situated at a depth of 15 feet and had a pipe length of 1000 feet.

The system with a pipe length of 1500 feet and a depth of 15 feet had the best running costs per tonnage. In comparison to a typical air conditioning system, the GSHP system reduces operating costs by more than 50%. These findings lead to the conclusion that Pakistan's household energy consumption can be reduced by the use of GSHP systems. Even though the GSHP system in Hayatabad, Peshawar, was thoroughly investigated in this research study, but much work still has to be done to reduce expenses and improve the system's functionality of the system to increase its effectiveness.

V. ACKNOWLEDGEMENT

The opportunity to write this acknowledgement brings me immense joy. The people that helped me finish my research work include my teachers, parents, relatives, and friends, especially Muhammad Shoaib. I will always be grateful to my supervisor, Dr. Salman Saeed, for his advice and his priceless time. The university's management deserves praise for providing the space needed for the GSHP model's installation and subsequent testing.

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