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Energy-Saving Potential of a Hybrid Ground Source Heat Pump with Energy Piles in Cooling Mode: A Case Study of a Green Academic Building in Bangkok, Thailand

Nut Neamnark[1†], Vasutorn Siriyakorn[1], Apiniti Jotisankasa[2], Attaporn Wisessint[3],
Kanet Katchasuwanmanee[3], Thongchart Kerdphol[1], Natthawut Chinthaned[1], Cheema Soralump[4],
and Peerayot Sanposh[1*]

[1]Department of Electrical Engineering, Kasetsart University, Bangkok, Thailand

[2]Department of Civil Engineering, Kasetsart University, Bangkok, Thailand

[3]Department of Mechanical Engineering, Kasetsart University, Bangkok, Thailand

[4]Department of Environmental Engineering, Kasetsart University, Bangkok, Thailand

(Tel: + 66-2-797-0999)

(E-mail: naaikido@hotmail.com, vasutorn.si@gmail.com, fengatj@ku.ac.th, fengapw@ku.ac.th,
kanet.k@ku.th, thongchart.k@ku.ac.th, fengnwc@ku.ac.th, fengcmc@ku.ac.th, peerayot.s@ku.ac.th)

[*]Corresponding author: peerayot.s@ku.ac.th

Abstract: The demand for air conditioners continues to rise, especially in high-temperature environments where their efficiency depends heavily on ambient conditions. As a result, air conditioners have become a significant source of energy consumption, leading to higher electricity bills. To address this issue, ground source heat pumps (GSHPs) provide cooling by transferring heat into the ground through ground heat exchangers (GHEs), relying on stable ground temperatures for optimal efficiency. This study is the first in Thailand to implement a hybrid ground source heat pump (HGSHP) in cooling mode by integrating an inverter-type air conditioner with a GSHP that utilizes the energy piles of a green academic building as a heat sink. In this cooperative HGSHP system, only a portion of the heat extracted from indoor spaces is transferred to the ground, while the remaining portion is discharged into the ambient air. In contrast, traditional systems, known as air-source heat pumps (ASHPs), discharge the entire heat load into the ambient air. Our HGSHP system enhances overall heat transfer efficiency compared to traditional ASHPs. The results indicate an energy reduction of 13.10% in compressor workload. Additionally, the integration of energy piles during building construction lowers installation costs and operational time associated with borehole drilling. This study underscores the potential of utilizing GSHPs with energy piles in short-term experiments to improve air conditioning system performance and offer an effective energy-saving solution.

Keywords: Air Conditioning, Ground Source Heat Pump (GSHP), Hybrid Ground Source Heat Pump (HGSHP), Ground Heat Exchanger (GHE), Energy Pile, Green Building.

1. INTRODUCTION

In tropical countries, air conditioners are essential for maintaining indoor comfort, making them into a major contributor to energy consumption [1]. In Thailand, where electricity costs are significant concern, nearly half of the electricity consumed in commercial buildings is dedicated for cooling indoor spaces [2]. This is achieved through air conditioning systems, which operate as air-source heat pumps (ASHPs) by exhausting heat from indoor spaces to the surrounding environment [3]. The effectiveness of this process depends on the ambient air temperature [4]. In densely populated areas with numerous units, heat accumulates in the environment, leading to an increase in ambient air temperature [5]. As a result, the system requires more electrical energy to transfer the indoor heat to the ambient air, reducing its efficiency and lowering its coefficient of performance (COP) [6]. Furthermore, during summer, when ambient temperatures are already high, the system has even fewer opportunities to achieve a high COP. To address this challenge, a stable, low-temperature heat sink is necessary.

The ground, used as a heat sink for ground source heat pumps (GSHPs) [7], provides an alternative method for transferring the heat from indoor spaces to the environment. In cooling mode, GSHPs transfer heat into the ground [8], unlike ASHPs. Due to the relatively stable ground temperature throughout the year [9], GSHPs generally achieve higher efficiency compared to ASHPs [10, 11]. This makes GSHPs an attractive option for energy-saving applications. Numerous studies have shown promising results regarding their efficient heat transfer capabilities [12, 13]. However, the widespread adoption of this system is limited due to high installation costs [14]. These costs can be significantly reduced if additional drilling for ground heat exchanger (GHE) installation is not required. Since building foundations typically require piles, incorporating GHEs into the unused space within these piles during construction can help lower GHE drilling costs [15]. Because the piles serve dual

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[†] Nut Neamnark is the presenter of this paper.

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Fig 1. Photographs of the experimental building (Kasetsart University, Bangkok, Thailand, December 6, 2024).

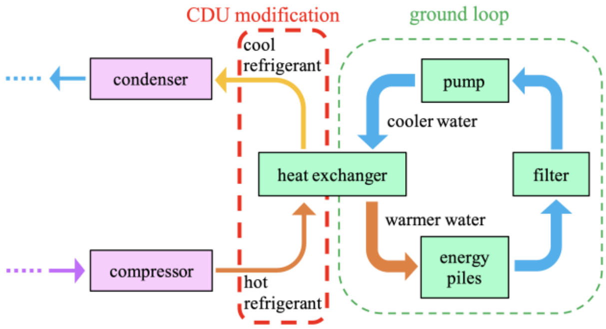


Fig 2. Schematic of the air conditioning system modified into a hybrid ground source heat pump (HGSHP) configuration utilizing energy piles.

purposes—acting as both the building foundation and GHE—they are referred to as energy piles [16]. In Thailand, GSHP systems with energy piles are still rarely used and primarily limited to research setups [17] and real-world utilizations.

To address this research gap, this paper proposes the first to implement a cooperative system that integrates GSHP and energy piles with an inverter-type air conditioning system in a green academic building. The air conditioner is connected to the building's energy piles through a heat exchanger which serves as a bridge for heat transfer. This setup allows a portion of the heat from the refrigerant to be transferred to the energy piles and ultimately to the surrounding ground, while the remaining heat is discharged through the condenser into the ambient air. This configuration is termed a hybrid ground source heat pump (HGSHP) utilizing energy piles, hereinafter referred to as the HGSHP system for brevity. It helps distribute the heat extraction load between the condenser and the ground, reducing compressor power consumption compared to the original system and providing an energy-efficient alternative. The experiment setup is located at the building in Kasetsart University's Faculty of Social Sciences in Bangkok, Thailand as shown in Fig. 1.

The structure of this paper is as follows: Section 2 describes the system configuration, Section 3 outlines the proposed methodology, Section 4 presents the experimental results, and Section 5 concludes with final remarks and directions for future research.

2. SYSTEM CONFIGURATION

2.1 Heat pump systems

Maintaining comfortable temperatures in living spaces is nearly impossible without heat pumps. In cooling applications, heat must be transferred from indoor spaces to an external medium, which is separated by a heat insulator. Heat pumps facilitate this process by extracting heat from a source and releasing it into a heat sink.

In equatorial regions, ASHPs are commonly used, utilizing ambient air as the heat sink. However, the efficiency of ASHPs is influenced by fluctuations in ambient air temperature due to varying weather conditions. Higher ambient temperatures hinder heat dissipation, increasing energy consumption and reducing system performance.

As an alternative to ambient air, GSHPs utilize the ground for heat dissipation. The ground's stable temperature, unaffected by weather fluctuations, provides a reliable medium for heat dissipation. This thermal stability enhances the efficiency of GSHPs compared to ASHPs, making them a more energy-efficient cooling solution.

2.2 Working principle of HGSHP system

The standard GSHP operates on thermodynamic principles, utilizing the ground as a heat sink. This concept of ground-based heat dissipation can be integrated into air conditioning systems that traditionally rely solely on ambient air as a heat sink. In a conventional air conditioning system, the refrigerant transfers heat from indoor spaces to the compressor and then directly to the condenser, where it is released into the ambient air, functioning as an ASHP.

In our modified HGSHP system, a portion of this heat is redirected to the ground via four additional components: a heat exchanger, an electrical pump, a water filter, and energy piles, as illustrated in Fig. 2. The newly added heat exchanger, located within the condensing unit (CDU) modification section (outlined by the red dashed frame), is positioned between the compressor and condenser. In this section, the hot refrigerant (represented by a thin orange arrow) transfers part of its heat to the water circulating in the ground loop before continuing to the condenser (represented by a thin yellow arrow).

On the water side of the heat exchanger, cooler water (indicated by a thick blue arrow) absorbs the heat and exits warmer (indicated by a thick orange arrow). The heated water is then directed to the energy piles, where the heat is dissipated into the ground. The cooled water returns through a water filter to remove potential contaminants, such as sand, before re-entering the circulation loop, which is driven by the electrical pump.

This HGSHP system provides an alternative cooling solution by utilizing both air and ground as heat sinks, thereby enhancing overall system efficiency.

2.3 Energy efficiency ratio (EER)

In a heat pump operating in cooling mode, system efficiency is evaluated using the energy efficiency ratio

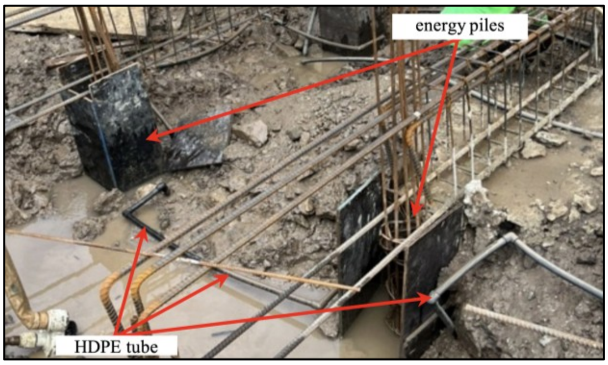


Fig 3. Photographs showing the energy piles during building's construction (Kasetsart University, Bangkok, Thailand).

(EER). The EER is defined as the ratio of the cooling capacity rate ($Q_{cooling}$ in W), representing the amount of heat removed from the room per unit time, to the electrical input power (P_{input} in W), as shown in Eq. (1) [18].

$$\text{EER} = \frac{Q_{cooling}}{P_{input}} \tag{1}$$

For most commercially available air conditioning systems, the EER value is provided by the manufacturer and is commonly used to compare efficiency across different systems. A higher EER value indicates greater efficiency, which can be achieved by either increasing the cooling capacity or reducing electrical power consumption.

2.4 Studied system

The energy piles are designed to function as vertical boreholes for the GHE. The system consists of 12 spun concrete piles covering an area of 30 square meters, with each pile reaching a depth of 21 meters. The ground loop utilizes High-Density Polyethylene (HDPE) tubing with a diameter of 0.0254 meters, installed in a single U-tube configuration within the energy piles [19]. The total available tubing length for heat exchange is 126 meters. The space between the HDPE tubing and the borehole walls is filled with water, facilitating efficient heat transfer. This energy pile design enables water surrounding the HDPE tubes to transport heat extracted from the building's experimental room to the surrounding ground.

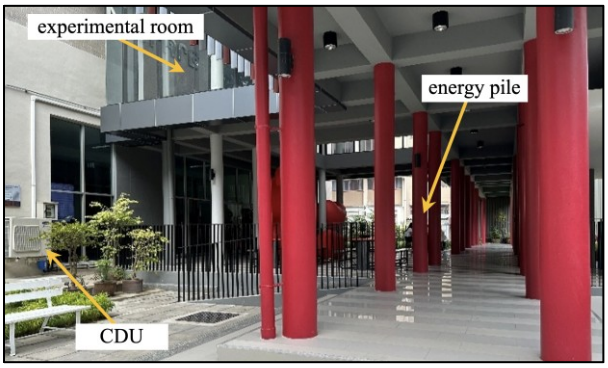
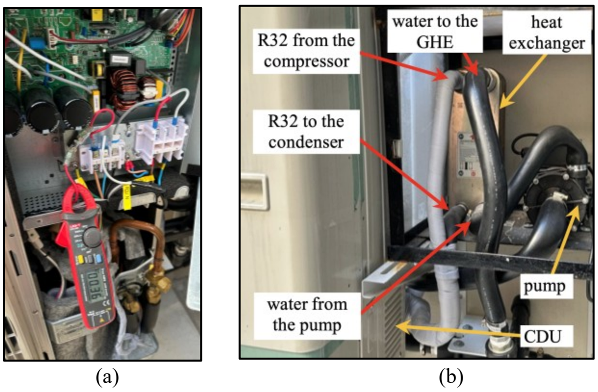


Fig 4. Photographs illustrating the locations of the experimental room, CDU, and an energy pile (Kasetsart University, Bangkok, Thailand, December 26, 2024).

The experimental room, located within the building as shown in Fig. 4, has a floor area of 179.3 square meters. The floor and ceiling are solid, while the walls consist of a combination of solid surfaces, glass panels, and glass doors, with glass covering most of the wall area. Six inverter-type air conditioning units are installed to cool the room; however, only one unit was modified and operated during the experiment. The fan coil unit (FCU) was installed on the ceiling and remained unaltered, whereas the CDU, located outdoors in the open air as shown in Fig. 4, underwent modifications to its internal refrigerant tubing to enhance heat transfer efficiency.

Originally, the R32 refrigerant flowed directly from the compressor to the condenser. In the modified system, the R32 refrigerant tubing is rerouted through a heat exchanger before reaching the condenser, as illustrated in the R32 refrigerant side diagram in Fig. 2 and practically in Fig. 5(b). The heat exchanger operates in a counter-flow arrangement, where the heat transfer fluids flow in opposite directions [20]. In this configuration, the R32 refrigerant enters the heat exchanger at the top and exits at the bottom.

On the water side, the heat exchanger is connected to a ground loop, where water circulates through an HDPE pipe, driven by an electric water pump. The water enters the heat exchanger at the bottom and exits at the top. This modification enables the system to release indoor heat both into the ambient air via the condenser and into the water circulating in the ground loop via the heat exchanger. The heated water is then dissipated into the ground through the energy piles, one of which is shown in Fig. 4.



(a) (b)

Fig 5. (a) Current measurement setup. (b) Overview of heat exchanger connection. (Kasetsart University, Bangkok, Thailand, December 10, 2024).

3. PROPOSED METHODOLOGY

3.1 Test configuration

These tests evaluate energy-saving performance by comparing a conventional air conditioning system to the HGSHP system. To achieve this, the system's energy consumption was measured under two operational scenarios:

Scenario 1: Baseline system (water pump off, without the GSHP). In this scenario, the system operates

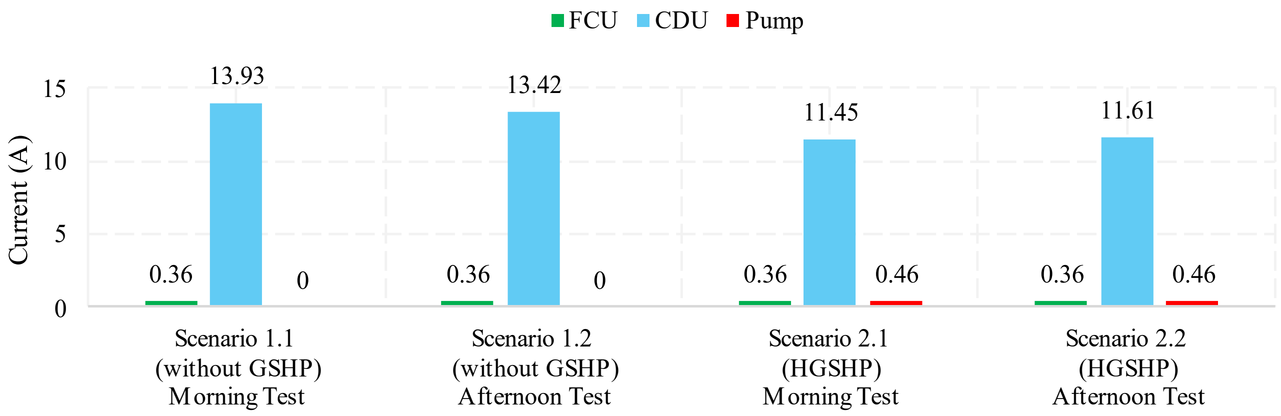


Fig 6. The mean current values for FCU, CDU, and water pump across four tests (two operational scenarios). Scenario 1.1 and 1.2 are the first and second tests of Scenario 1, respectively; Scenario 2.1 and 2.2 are for Scenario 2.

as a conventional air conditioner, where all heat from the indoor space is fully transferred to the ambient air via the condenser. This setup represents the baseline energy consumption.

Scenario 2: HGSHP system (water pump on, with the GSHP active). In this scenario, heat dissipation occurs through both the ambient air and the ground. The heat exchanger diverts a portion of the heat to the ground loop, where it is dissipated into the ground via the energy piles. This setup represents the modified system's energy consumption.

The scenarios were controlled by switching the water pump on or off. Energy measurements were conducted with the compressor operating continuously at full cooling load to ensure consistent experimental conditions.

3.2 Energy saving potential evaluation

Since the incoming voltage supplying all devices remained constant, the system's efficiency before and after modification was compared based on the current drawn by the system. In Scenario 1, where the system operated without the GSHP (as a conventional air conditioner), the total electrical input power was the sum of the power consumed by the FCU and the CDU. In Scenario 2, where the system operated as an HGSHP, the water pump was running; thus, the total electrical input power included the contributions from the FCU, CDU, and the water pump used for water circulation in the ground loop. The current drawn by each device was measured using a clamp meter attached to the relevant components, as illustrated in Fig. 5 (a). For example, a clamp meter was used to measure the FCU's current by clamping around its hot line wire, which showed a reading of 0.36 A. The measured current represents the power consumption of each device and serves as an indicator of the energy-saving potential of the modified system.

4. EXPERIMENTAL RESULTS

4.1 Experimental setup and conditions

The outcomes were derived from tests conducted over two consecutive days under similar weather conditions. Four tests were performed to evaluate the system under two scenarios, as described in Section 3.1. Each scenario was tested twice during two time slots: morning (10:00 AM – 12:00 PM) and afternoon (1:00 PM – 3:00 PM). Throughout the tests, data were recorded multiple times at reasonable intervals. The experimental room temperature, measured 3 meters below the FCU, ranged from 29.2°C to 30.3°C. The ambient temperature, measured outside the experimental room in a shaded area to avoid direct sunlight, ranged from 31.4°C to 35.6°C, reflecting variations in weather conditions.

4.2 Electrical parameters and device performance

The voltage across all devices in the system remained stable, with an average value of 223.9 V. The power factors of the CDU and the electrical pump were 0.95 and 0.72, respectively. The mean current drawn by each system device during each test is presented in Fig. 6 for comparison.

In Scenarios 1.1 and 1.2, where the air conditioner operated without the GSHP, the mean current drawn by the CDU during the morning test was 13.93 A, which was higher than the 13.42 A recorded during the afternoon test. This difference was attributed to minor environmental variations. Consequently, the overall average current drawn by the CDU in this scenario was 13.67 A. As no water pump was used in this setup, its current draw is represented as zero in the bar graph. The FCU maintained a constant current draw of 0.36 A throughout the tests.

In Scenarios 2.1 and 2.2, where the HGSHP system was in operation, the mean current drawn by the CDU during the morning test was 11.45 A, which was slightly lower than the 11.61 A recorded in the afternoon test, likely due to minor environmental variations. Consequently, the overall average current drawn by the CDU decreased to 11.53 A. The water pump, operating continuously, maintained a constant current draw of 0.46 A, while the FCU consistently drew 0.36 A.

4.3 System performance

The experiments revealed significant differences in system performance between the two scenarios. When operating at full cooling load, the FCU consistently transferred indoor heat to the refrigerant, drawing 0.36 A in both scenarios.

Table 1 Average Current and Power Consumption

Scenarios	**Average current (A)**		**Average power (W)**	
	CDU	**Pump**	**CDU**	**Pump**
Without GSHP	13.67	0	2907.68	0
HGSHP	11.53	0.46	2452.48	74.15

In Scenarios 1.1 and 1.2, without the GSHP, the CDU relied solely on the condenser to dissipate heat from the refrigerant, resulting in a higher average current draw of 13.67 A, as shown in the Table 1, with an energy consumption of 2907.68 W. This indicates increased power consumption as the system worked harder to lower the refrigerant temperature.

In Scenarios 2.1 and 2.2, with the HGSHP system, the energy piles functioned as an additional heat sink, providing greater surface area for heat dissipation into the environment. This reduced the compressor's workload, leading to a significant decrease in the CDU's current draw to 11.53 A as shown in Table 1, with energy consumption of 2452.48 W. The water pump, which drew a constant 0.46 A, also contributed to the total consumption, as shown in Table 1 with an energy use of 74.15 W. The total power consumption was 2526.63 W. The overall system energy consumption was more efficient compared to operation without the GSHP, showing a reduction of 381.05 W, which corresponds to a 13.10% energy saving.

The efficiency improvement is also evident in the increased EER value when the GSHP and energy piles were integrated into the system. Since the compressor operated continuously at maximum cooling capacity in both scenarios, the reduced current draw resulted in lower overall power consumption. As indicated in Eq. (1), the EER of our HGSHP system increased as the denominator, representing power consumption, decreased. These findings underscore the potential of integrating GSHP and energy piles into air conditioning systems to reduce power consumption and enhance energy efficiency.

5. CONCLUSION

This study evaluates the short-term energy-saving potential of a modified inverter air conditioning system based on GSHP principles, incorporating energy piles as an auxiliary heat dissipation mechanism. By transferring a portion of the indoor heat to the ground, this modification reduces the CDU's running current compared to the original system, leading to lower power consumption and an improved EER, demonstrating enhanced system efficiency and electricity cost savings.

Furthermore, the integration of energy piles significantly reduces borehole installation time and costs compared to traditional post-construction methods, offering a cost-effective approach to integrating GSHP technology with air conditioning systems. The findings highlight the potential of this alternative energy-saving solution.

Future research will focus on integrating IoT technology to enable real-time monitoring and data collection from the HGSHP system across diverse environmental conditions. This will provide deeper insights into system performance, energy consumption patterns, and operational efficiency under varying loads and climates. The expanded data set will facilitate optimization strategies and improve the adaptability of the system for broader applications.

In addition, future work will include long-term monitoring to assess seasonal performance and durability, a detailed cost-benefit analysis to demonstrate economic viability, evaluation of environmental impacts such as carbon footprint reduction, and comparative studies with other energy-efficient cooling technologies to benchmark performance and effectiveness.

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