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Optimizing Heat Recovery from Split AC Systems for Water Heating: Performance Analysis of Helical Coil Configurations and Power Capacities

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ABSTRACT

This study explores the efficient utilization of waste heat energy from the outdoor unit of a split air conditioning system to heat water using a helical coil configuration. We investigated various configurations within a 60-liter tank, focusing on split air conditioners with capacities of 1/2 PK, 1 PK, and 2 PK, and tested helical coils with diameters of 15 cm, 25 cm, and 30 cm, and turns of 5, 10, and 15. Data on compressor, condenser, and water temperatures were systematically collected to assess heating efficiency and duration. Our findings reveal that both air conditioner capacity and coil design significantly influence heating performance. Notably, the 2 PK air conditioner paired with a 30 cm coil and 15 turns achieved a maximum water temperature of 57.72℃ within 105 minutes, compared to 49.52℃ in 120 minutes for the 1 PK unit, and 44.72℃ in 135 minutes for the 1/2 PK unit. This research underscores the potential for optimizing helical coil configurations to enhance heat transfer efficiency, offering an effective and energy-efficient alternative to conventional water heating methods while reducing operational costs.

1. INTRODUCTION

The utilization of residual energy from split air conditioning systems to heat water represents a novel approach that aligns with global efforts to enhance energy efficiency and reduce operational costs. This technology harnesses the exhaust heat from the outdoor unit of split air conditioners—typically considered waste—and employs a helical coil system to optimize heat transfer and improve water heating efficiency.

A split air conditioning system consists of an indoor unit that absorbs heat from the indoor air and an outdoor unit that releases this heat into the environment. While effective in regulating room temperature, the heat generated by outdoor units often remains untapped. By leveraging this waste heat for water heating, we can provide a sustainable alternative to traditional water heaters, which reduces energy consumption and lowers operational costs. Furthermore, waste heat from the air conditioning condenser can be repurposed for processes such as desiccant wheel regeneration, further enhancing overall system efficiency [1].

Split air conditioner-based water heaters utilize helical coils to transfer heat from refrigerant to water. These coils, designed as circular tubes inside water tanks, maximize the contact surface area between the refrigerant and water, thereby improving heat transfer efficiency and accelerating the heating process. Research indicates that variations in compressor capacity significantly influence heating efficiency; for instance, a study demonstrated that the average heating capacity of heat pumps decreased by 12% on colder days, with a 20% reduction in the coefficient of performance (COP) during simultaneous compressor operation [2].

Additionally, inverter air conditioners have been shown to save up to 44% in electrical energy consumption compared to non-inverter systems [3]. Studies also suggest that coupling split-type air conditioning systems with cooling panels can enhance cooling capacity by 0.43% while reducing power consumption by 2.47% [4]. Furthermore, it was found that the COP of air source heat pumps (ASPK) increased from 3.38 to 5.49 as outdoor temperatures rose from -10℃ to 18℃, highlighting the influence of power variations on heating performance [5]. Research on the impact of on-off cycling losses on the energy performance of reversible water-to-water heat pumps shows that energy losses due to on-off cycles greatly affect system performance, especially for single-stage units that frequently cycle on and off [6]. These findings are particularly relevant for studies on water heaters that use split AC power, as they provide insight into how power variations can affect system efficiency. An evaluation of variable capacity heat pumps in cold climates indicates that these systems have significant energy-saving potential in heating applications for residential buildings in Canada [7]. This study examines the utilization of waste heat from cooling and air conditioning systems for water heating, water cooling, and air cooling in a single multifunctional unit, with results showing a system COP of 4.03 [8]. This research is crucial for understanding how variations in power capacity affect heating efficiency in water heating systems that use split AC power, particularly under different environmental conditions. On the other hand, previous research on the effects of using helical coils as heaters has explored their application in water heating systems, where the development of new air heaters integrating microwave heating with thermal energy storage using helical coils has significantly improved heat transfer efficiency [9]. Additionally, improved thermal performance of solar energy receivers with carbon nanostructure-coated helical coil designs demonstrates that such coatings can significantly enhance thermal efficiency [10]. An analysis of the heat and mass transfer performance of fan coils in air conditioning systems shows that variations in the temperature of the cooling water affect cooling capacity; however, proper design of the fan coil can compensate for decreases in efficiency [11].

Despite the significant research into the individual aspects of split AC systems and helical coil designs, a critical gap remains in understanding their combined effects on water heating efficiency. Existing literature tends to focus on isolated parameters, such as either the design of helical coils or the power capacity of split AC systems, without examining the interplay between the two. This study aims to bridge this gap by investigating how variations in split AC power capacity and helical coil configurations jointly affect water heating efficiency.

To address this gap, we will conduct experiments with different helical coil configurations and split AC power capacities. Specifically, we will test helical coils with diameters of 15 cm (5 turns), 25 cm (10 turns), and 30 cm (15 turns), all utilizing a pitch of 2 cm at split AC power capacities of 1/2 PK, 1 PK, and 2 PK. The analysis will focus on measuring water heating efficiency, energy consumption, and heating time across these configurations. Collected data will include water temperature, heating duration, and energy consumption, with findings compared against previous studies to discern significant patterns and trends.

The anticipated outcomes of this research are twofold: first, to provide valuable insights into the integration of split air conditioning and water heating technologies, thereby contributing to the HVAC industry; and second, to offer practical solutions that can lower energy costs and mitigate environmental impacts for end users. This research could also support energy and environmental policies advocating sustainable technologies and reduced carbon emissions, paving the way for further investigations into optimizing split air conditioner-based water heating systems in various environmental contexts and exploring other water heating technologies.

2. METHODOLOGY

The goal of this study is to explore how different power capacities of split air conditioning (AC) units and helical coil configurations affect water heating efficiency. We've established a clear methodology involving four key stages: experiment design, data collection, data analysis, and result validation. Each stage is carefully designed to guarantee the precision, reproducibility, and applicability of our findings in both practical and theoretical contexts. Here is a concise description of each step in our methodology.

2.1 Experimental planning

2.1.1 System design

This study aims to evaluate the performance of a helical coil-based water heating system integrated with split air conditioning units of varying capacities: 1/2 PK, 1 PK, and 2 PK. The helical coils will be tested under different configurations, focusing on three key parameters: coil diameter, number of turns, and pitch. The specific configurations to be examined include:

Coil diameters: 15 cm, 25 cm, 30 cm
Number of turns: 5, 10, 15
Pitch: 2 cm

This variation will allow us to assess the influence of each parameter on water heating efficiency, energy consumption, and heating time

2.1.2 Equipment and materials

Split Air Conditioning units. Three AC units with different power capacities, namely 1/2 PK, 1 PK, and 2 PK.

The choice of split AC units with capacities of 1/2 PK, 1 PK, and 2 PK is grounded in their widespread use in residential and commercial settings. These capacities represent a range of common applications, allowing for a relevant assessment of performance across different scenarios. By using units with different capacities, the study can evaluate how varying power inputs impact water heating efficiency. Each unit will operate under similar environmental conditions, ensuring a controlled comparison that highlights differences due to capacity rather than external factors.

Helical coils. Coil with a variation in diameter (15 cm, 25 cm, 30 cm), number of turns (5, 10, 15), and fixed pitch (2 cm).

Helical coils are selected for their efficiency in heat transfer due to their geometric design, which allows for enhanced contact between the heating medium (water) and the heating source (refrigerant). The parameters of diameter, number of turns, and pitch are varied to understand their individual effects on heating efficiency. The specific configurations (15 cm, 25 cm, 30 cm diameters; 5, 10, 15 turns; 2 cm pitch) are chosen based on prior research indicating optimal designs for heat exchange. Testing multiple configurations allows for a thorough investigation of how each parameter influences performance, providing clear data for analysis.

Water tank. A tank with a capacity of 60 liters used in each test. A 60-liter water tank is selected to balance the practical aspects of water heating and the feasibility of experimentation. This size is manageable for testing and allows for sufficient water volume to generate measurable temperature changes. The tank is used consistently across all tests to ensure uniformity in heat transfer conditions. By maintaining the same volume, variations in heating efficiency can be attributed solely to the AC and helical coil configurations rather than differences in the heating medium.

Temperature sensor. MAX6675 temperature sensor is used to measure the temperature of compressors, condensers and water during the heating process.

The MAX6675 temperature sensor is chosen for its accuracy and reliability in measuring temperatures in HVAC applications. Accurate temperature readings are critical for assessing system performance and ensuring valid results. The sensors are calibrated before testing to ensure precise measurements. Recording temperatures at 15-minute intervals allows for detailed monitoring of the heating process, providing a robust dataset for analysis.

2.1.3 The basis for selection equipment

Split air conditioning units. Selecting units with capacities of 1/2 PK, 1 PK, and 2 PK allows for a comprehensive analysis of how variations in power input affect water heating efficiency. These capacities represent common usage in both residential and commercial applications. These units are frequently used in existing HVAC systems, making the research results applicable to real-world conditions.

Helical coils. Helical coils are chosen for their design that facilitates improved heat transfer efficiency. This is essential for achieving optimal heating results. Varying the diameter, number of turns, and pitch of the coils provides deeper insights into how each factor influences heating performance.

Water tank. A 60-liter tank is selected to hold a sufficient volume of water to produce significant temperature changes during testing. This size strikes a balance between practicality and representativeness for heating applications. Using the same tank size throughout the experiments ensures uniformity in heat transfer conditions, allowing variations in results to be attributed solely to the configurations of the AC unit and helical coil.

Temperature sensor. The MAX6675 sensor is chosen for its accuracy in measuring temperature, which is crucial for collecting valid and reliable data. This accuracy ensures that the research results reflect the actual performance of the system. This sensor is designed for HVAC applications, making it easy to integrate into the systems being tested.

2.2 Data collection

2.2.1 Experimental procedure

Preparation. Each helical coil configuration is installed in a water tank and connected to a split AC unit that corresponds to a predetermined power capacity.

Initial testing. The system is run in initial conditions without heating to ensure all tools and sensors are functioning properly.

Water heating. The split System AC unit is activated to heat the water in the tank. Water temperature data is recorded at 15-minute intervals until it reaches the target temperature.

Data collection. During the heating process, the water temperature and the time it takes to reach the target temperature are recorded for each configuration.

2.2.2 Parameter variations

Split AC power capacity. Testing is performed for each AC power capacity (1/2 PK, 1 PK, 2 PK) with all helical coil configurations.

Helical coil configuration. Each coil diameter (15 cm, 25 cm, 30 cm), number of turns (5, 10, 15), and pitch 2 cm are tested at all AC power capacities.

2.3 Data analysis

This section outlines the analytical approach employed to evaluate the effects of helical coil configurations and split AC power capacities on water heating efficiency. The analysis focuses on three main aspects:

Temperature analysis. Examination of the compressor, condenser, and water temperatures produced based on variations in helical coil configurations and AC power capacities.

Impact of AC power capacity and helical coil design. Assessment of how variations in AC power capacity and helical coil design influence water heating performance.

Time to reach target temperature. Evaluation of the time required to achieve the target temperature for each configuration and power capacity, along with an analysis of the effects of coil diameter, number of turns, and pitch on heating time.

Figure 1 illustrates the schematic of an air-conditioning (AC)-based water heating system that utilizes waste heat from the compressor to heat water in a tank, using a coil as the heat exchanger. The refrigerant temperature is measured before and after entering the tank (T_1, T_2), while the water temperature inside the tank (T_w) is monitored using sensors connected to an Arduino for real-time data logging. This system integrates energy-saving technology with precise temperature monitoring, contributing to the development of an efficient and environmentally friendly water heater.

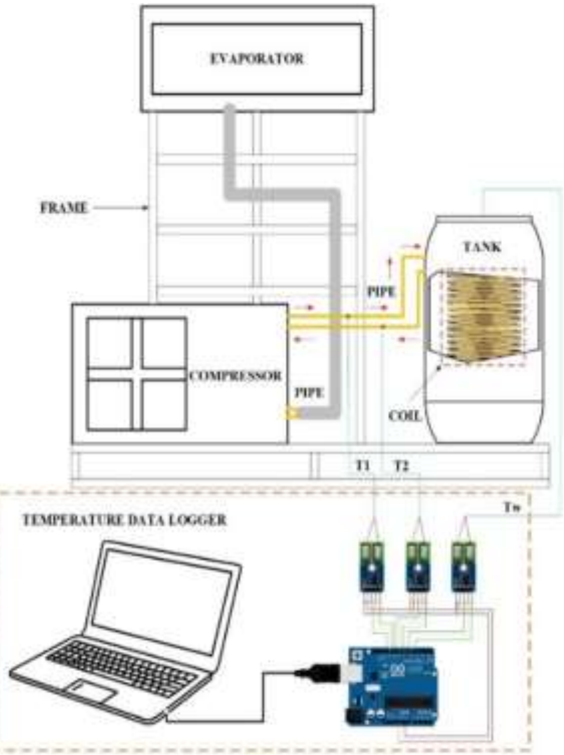

Figure 1. Schematic diagram of the AC water heater

Figure 2. AC water heater 1/2, 1 and 2 PK

In contrast, Figure 2 showcases a prototype system consisting of three AC units with different capacities (1/2 PK, 1 PK, and 2 PK), each connected to a water tank equipped with a coil for heating. These tanks are thermally insulated to reduce heat loss. Temperature data from each system is electronically logged and analyzed using a laptop. This prototype aims to test the efficiency of water heating at various AC capacities and optimize energy use in a more sustainable household water heating system.

3. RESULT AND DISCUSSION

3.1 Test result data

The data obtained from the test results conducted in this study will be elaborated upon in the discussion to elucidate the desired variables. Below are the test results pertaining to the heat transfer occurring from the helical coil to the water. During the testing process, data on compressor temperature, condenser temperature, and water temperature were collected while the indoor air conditioner was set to a temperature of 16°C. Data collection was conducted for each air conditioner type and helical coil configuration, with temperature measurements taken every 15 minutes using a temperature sensor.

Across all tables, higher AC power consistently shortens stabilization time. A 2 PK AC always achieves the shortest stabilization time (105 minutes) in all helical coil configurations. Conversely, the lowest power (1/2 PK) requires the longest stabilization time (135 minutes). Increased AC power also raises compressor, condenser, and water temperatures. For instance, with a 15 cm diameter coil and 5 turns (Table 1), 2 PK results in a water temperature of 51.72°C, whereas 1/2 PK only reaches 40.78°C. Similar trends are observed for 25 cm and 30 cm diameter coils (Tables 2 and 3), with maximum water temperatures of 54.52°C and 57.72°C, respectively, at 2 PK.

Larger coil diameters and greater numbers of turns improve heating efficiency but also increase compressor temperatures, evident from the rise in compressor temperature across all tables. In a 15 cm diameter coil with 5 turns (Table 1), maximum compressor temperature at 2 PK reaches 79.59°C. However, in a 30 cm diameter coil with 15 turns (Table 3), compressor temperature escalates to 84.95°C at the same power. Thermal efficiency improves with larger coil diameters, especially in terms of increased water temperature. In a 15 cm diameter coil (Table 1), the highest water temperature achieved is 51.72°C, whereas with a 30 cm diameter coil (Table 3), water temperature rises to 57.72°C at 2 PK. This indicates that increasing coil diameter and number of turns enhances heat transfer from the compressor to the water more effectively.

Consistently across all tables, both stabilization time and temperatures increase with increasing coil diameter and AC power. For example, with a 15 cm diameter and 5 turns (Table 1), the maximum water temperature achieved is 51.72°C at 2 PK, while in a 30 cm diameter and 15 turns (Table 3), the same water temperature is reached at 57.72°C with 2 PK. This pattern underscores that AC-based water heating systems with larger coils and more turns are more efficient in achieving higher temperatures with faster stabilization times, particularly at higher AC powers.

The following section provides a detailed examination of the effects of various helical coil configurations with differing diameters on the performance of 1/2 PK, 1 PK, and 2 PK air conditioners. The specific diameters under consideration include 15 cm (5 turns), 25 cm (10 turns), and 30 cm (15 turns).

3.2 Power variation effects

3.2.1 Compressor temperature analysis

The capacity of an air conditioner, measured in horsepower (PK), plays a crucial role in the process of heating water. It determines the energy available for compressing the refrigerant, which subsequently generates heat. As the capacity of the air conditioner increases, so does the temperature produced by the compressor and condenser. A larger capacity necessitates greater compressor effort to compress a larger volume of refrigerant, resulting in increased heat generation.

The helical coil functions as a heat transfer medium, efficiently conveying heat from the refrigerant to the water. Air conditioners with higher capacities can transfer more heat to the helical coil, significantly elevating the water temperature compared to those with lower capacities. Research indicates that higher air conditioner capacity correlates with increased maximum water temperatures. For instance, a 2 PK air conditioner utilizing a helical coil with a diameter of 30 cm and 15 turns can heat water to 57.72°C, while a 1 PK unit reaches only 49.52°C, and a 1/2 PK unit achieves a maximum of 44.72°C. Thus, for applications necessitating elevated water temperatures, it is advisable to utilize air conditioners with larger capacities.

Table 1. Helical coil test data (diameter: 15 cm, turns: 5, pitch: 2 cm)

AC Power (PK)	Stabilization Time (Minutes)	Compressor Temperature (°C)	Condenser Temperature (°C)	Water Temperature (°C)
1/2	135	64	46.22	40.78
1	120	74	51	46.72
2	105	79.59	54.95	51.72

Table 2. Helical coil test data (diameter: 25 cm, turns: 10, pitch: 2 cm)

AC Power (PK)	Stabilization Time (Minutes)	Compressor Temperature (°C)	Condenser Temperature (°C)	Water Temperature (°C)
1/2	135	70	47	42
1	120	76.25	51	47.18
2	105	82.52	59.88	54.52

Table 3. Helical coil test data (diameter: 30 cm, turns: 15, pitch: 2 cm)

AC Power (PK)	Stabilization Time (Minutes)	Compressor Temperature (°C)	Condenser Temperature (°C)	Water Temperature (°C)
1/2	135	72	49	44.72
1	120	77.15	54.25	49.52
2	105	84.95	63.92	57.72

Moreover, the capacity of the air conditioner also influences the time required to attain a stable temperature. Higher-capacity units achieve stable temperatures more rapidly due to their enhanced heat transfer capabilities. For example, a 2 PK air conditioner stabilizes within 105 minutes, while a 1 PK unit takes 120 minutes, and a 1/2 PK unit requires 135 minutes. Consequently, for scenarios demanding quick temperature stabilization, larger capacity air conditioners are preferable.

The compressor temperature is a critical parameter influencing the performance and efficiency of an air conditioning system. This study investigates the correlation between air conditioner capacity, compressor temperature, and their impact on overall system performance. The collected data indicate a direct relationship: as the capacity of the air conditioner increases, so does the compressor temperature. This is primarily attributed to the heightened workload on the compressor to accommodate the increased refrigerant flow. The findings of this research align with existing literature, offering valuable insights into the interplay between compressor temperature and air conditioning capacity. They underscore the significance of factors such as compressor efficiency, lubricant properties, and system design in optimizing compressor performance [12-18].

3.2.2 Condenser temperature analysis

The temperature of the condenser rises in tandem with the capacity of the air conditioner. In systems with larger capacities, such as 2 PK air conditioners, the amount of heat that needs to be dissipated by the condenser increases significantly. For instance, data obtained from helical coils with diameters of 30 cm and 15 turns reveal that the condenser temperature reaches 49°C in a 1/2 PK AC, 54.25°C in a 1 PK AC, and can escalate to 63.92°C in a 2 PK AC. This increase in condenser temperature underscores the greater heat load the condenser must manage during the condensing process.

Elevated condenser temperatures have several critical implications, including an increased workload on the condenser, diminished thermal efficiency, and heightened energy consumption. However, the higher condenser temperatures also enhance the efficiency of heat transfer to water through the helical coil, facilitating quicker heating and allowing the water to achieve elevated temperatures more rapidly.

3.2.3 Water temperature analysis in tubes

The analysis of the tubes indicates that the capacity of the air conditioner has a direct impact on the temperature of the water within the tubes. Larger capacity air conditioners, such as those rated at 2 PK, can generate significantly more heat during the compression and condensation processes, thereby facilitating a more efficient transfer of heat to the water. Consequently, higher water temperatures can be achieved in a shorter time frame compared to their smaller capacity counter par. The temperature of the water in the tube is intricately linked to the temperatures of both the compressor and condenser. As compressors compress refrigerants, they generate substantial heat, which is subsequently transferred to the condenser. In the condenser, the refrigerant releases heat before it flows through the helical coil in the heating tube.ts.

The increased temperatures of the compressor and condenser provide a greater amount of heat available for transfer to the water. For instance, in a 1/2 PK air conditioner, with a compressor temperature of approximately 72°C and a condenser temperature of around 49°C, the water temperature can reach 44.72°C. In contrast, an AC unit rated at 1 PK exhibits a compressor temperature of about 77.15°C and a condenser temperature of approximately 54.25°C, resulting in a water temperature of 49.52°C. For the 2 PK air conditioner, with a compressor temperature of around 84.95°C and a condenser temperature of 63.92°C, the water temperature can reach up to 57.72°C.

3.2.4 Temperature stabilization time

The stabilization time of water temperature is a critical parameter in water heating systems utilizing split air conditioning. It reflects the duration required for the water to reach and maintain the desired temperature. Several factors influence this parameter, including the capacity of the air conditioner, the design of the helical coil, the initial water temperature, and prevailing environmental conditions.

Data collected from the study indicate that stabilization time varies significantly with the air conditioner's capacity. In a 1/2 PK air conditioner, the stabilization time is approximately 135 minutes, while a 1 PK unit achieves stabilization in 120 minutes. Remarkably, a 2 PK air conditioner requires only 105 minutes for stabilization. This difference can be attributed to the higher heat transfer rates from the compressor and condenser to the water in systems with larger capacities.

Temperature stabilization refers to the period during which the water in the heating tube attains and maintains the target temperature with minimal fluctuations. This process includes preheating the water until it reaches a stable point where the rate of heat gain equals the rate of heat loss.

The initial temperature of the water also plays a significant role in stabilization time. Water starting at a temperature closer to the target stabilizes more rapidly compared to water that begins at a considerably lower temperature. Furthermore, environmental factors, such as ambient temperature and ventilation around the condenser, impact the efficiency of heat transfer. Optimal environmental conditions, characterized by good ventilation, enhance the effective release of heat from the condenser, thereby accelerating the water heating process.

3.3 Effect of helical coil variation

The design of the helical coil is instrumental in determining both heat transfer efficiency and temperature stabilization time within a water heating system. Helical coils with a diameter of 30 cm, comprising 15 turns and a pitch of 2 cm, have demonstrated superior effectiveness in transferring heat from the refrigerant to the water. This specific design maximizes contact between the refrigerant and the water, thereby enhancing the heat transfer rate and minimizing the time required to achieve temperature stabilization. Optimal coil design not only improves efficiency but also accelerates the system's ability to reach the target temperature while ensuring better maintenance of the water heating system.

Numerous studies corroborate the assertion that an appropriately designed coil can significantly enhance the overall performance of water heating systems, leading to faster heating times and improved thermal management.

According to research, using a variable pitch on the condenser coil significantly increases the heat transfer coefficient and average COP compared to a constant pitch. Reducing the pitch and coil diameter can also raise the average water temperature [19]. Increasing the coil diameter significantly enhances the Nusselt number, the overall coefficient of performance (COP) of the refrigeration cycle, and the destroyed exergy, with other parameters held constant [20]. In a three-fluid heat exchanger with a helical coil, the volumetric flow rate of hot water is the main factor influencing heat transfer [21]. Heat transfer coefficients and COP increase with variable coil diameters compared to fixed diameters [22]. This research aligns with previous studies that noted the use of helical coil heat exchangers significantly enhances air conditioning system efficiency. The study particularly showed an increase in the coefficient of performance (COP) and the difference in water outlet temperature using helical coil configurations [23, 24].

Increasing the pitch of the coil improves the contact between the hot fluid and the coil, resulting in a lower outlet temperature of the hot fluid [25]. The flow rate of cold water has the greatest impact on the Nusselt figure and friction factor in a multi-fluid heat exchanger for simultaneous heating of water and air [26].

The material of the helical coil also plays a crucial role in heat transfer efficiency. Materials with high thermal conductivity, such as the copper used in this study, facilitate faster and more efficient heat transfer. This not only helps achieve stable temperatures faster but also ensures longer stability by minimizing heat loss during transfer. Using the right materials optimizes the performance of the water heating system and reduces stabilization time. This aligns with research on the materials used in helical coils, which have a significant impact on heat transfer efficiency. This study is consistent with previous research that states the use of materials with high thermal conductivity, like copper, can markedly improve heat transfer efficiency [27-31].

3.3.1 AC 1/2 PK

Helical coil diameter 15 cm (turn 5). Effect on compressors and condensers: In a 1/2 PK air conditioner, the cooling capacity is relatively small, resulting in a reduced amount of refrigerant circulating through the system. When paired with a helical coil measuring 15 cm in diameter and 5 turns, the limited contact area between the refrigerant and water slows down the heat transfer process. Consequently, the compressor and condenser experience a more rapid temperature increase, as the refrigerant is not sufficiently cooled before entering the condenser. Compared to 1 PK or 2 PK systems, a 1/2 PK air conditioner has a significantly lower cooling capacity. This lower capacity, combined with a reduced refrigerant load, means that variations in the helical coil design have a less pronounced effect on temperature reduction in the compressor and condenser. The smaller coil diameter and fewer turns contribute to increased refrigerant pressure, accelerating heat buildup and leading to higher temperatures in both the compressor and condenser. This phenomenon is consistent with temperature rise observed in closed channels with limited heat transfer efficiency.

Effect on water temperature: In terms of water temperature, a helical coil with fewer turns and a smaller diameter exhibits reduced heat transfer capability, resulting in lower water temperatures in the tank and prolonged heating times. Additionally, the smaller capacity of the 1/2 PK system extends the time required to heat the water compared to larger air conditioning systems. While variations in the helical coil design can enhance heat transfer efficiency, these improvements are more pronounced over extended periods, highlighting the system's limitations in short-term performance.

Helical coil diameter 25 cm (10 turns). Effect on compressors and condensers: With a coil of larger diameter at 25 cm and 10 turns, the heat transfer efficiency improves. Consequently, the temperatures of the compressor and condenser can be maintained at lower levels, even with the limited cooling capacity of 1/2 PK. This increased efficiency helps lower the compressor's working pressure. Additionally, the larger coil diameter and greater number of turns enhance heat transfer to the water, resulting in a faster rise in water temperature compared to a coil with a diameter of 15 cm.

Effect on water temperature**:** In a 1/2 PK system, a coil with a diameter of 30 cm and 15 turns may not be fully optimized, as the refrigerant flow may be insufficient to maximize the coil's heat transfer capacity. While the compressor and condenser temperatures remain stable, the efficiency gains are modest compared to systems with larger capacities. Although this coil exhibits excellent heat transfer performance, the rate of water temperature increase is slower in a 1/2 PK system due to its limited cooling power.

Helical coil diameter 30 cm (turn 15). Effect on compressors and condensers: In a 1/2 PK system, using a coil of this size may not be fully optimal, as the refrigerant volume may be insufficient to fully utilize the coil’s heat transfer capacity. Although the compressor and condenser temperatures remain stable, the efficiency gains are relatively modest compared to systems with larger capacities.

Effect on water temperature**:** This coil offers optimal heat transfer performance; however, in a 1/2 PK system, the increase in water temperature will not occur as rapidly as in larger systems due to the limited cooling capacity.

3.3.2 AC 1 PK

Helical coil diameter 15 cm (5 turns). Effect on compressors and condensers: In a 1 PK air conditioner, a small coil with fewer turns will yield similar effects as in a 1/2 PK system. However, due to the larger system capacity, the compressor and condenser must exert more effort to maintain optimal operating temperatures, particularly under high-load conditions. In a 1 PK system, the impact of helical coil variations is more pronounced than in a 1/2 PK system, attributed to the greater refrigerant flow and enhanced capacities of the compressor and condenser. Helical coils with larger diameters and more turns can significantly improve heat transfer efficiency, lower temperatures in the compressors and condensers, and enhance the system's COP [32].

Effect on water temperature: This coil will provide limited heat transfer, leading to a slower increase in water temperature within the tank compared to a larger coil.

Helical coil diameter 25 cm (10 turns). Effect on compressors and condensers: In the 1 PK system, this coil enhances the heat transfer balance, allowing for better control of compressor and condenser temperatures. The water absorbs heat from the refrigerant more effectively before it reaches the condenser, resulting in improved thermal management.

Effect on water temperature: The water temperature in the tank will rise at a moderate rate, attributable to the larger surface area of the coil, which facilitates more efficient heat transfer compared to a coil with a diameter of 15 cm.

Helical coil diameter 30 cm (15 turns). Effect on compressors and condensers: In a 1 PK air conditioner, this larger coil maximizes heat transfer capacity, enabling the compressor and condenser to operate at lower temperatures. This reduction in temperature decreases pressure, thereby enhancing the overall lifespan of the system.

Effect on water temperature: This coil rapidly increases the water temperature due to its extensive surface area and multiple turns, thereby enhancing the efficiency of the water heating process.

3.3.3 AC 2 PK

Helical coil diameter 15 cm (5 turns). Effect on compressors and condensers: In a 2 PK system, this small coil proves to be highly inefficient. The compressor and condenser must exert additional effort as the coil struggles to accommodate the larger refrigerant flow effectively, resulting in a rapid increase in temperature within both components. The coil's smaller diameter and fewer turns contribute to elevated refrigerant pressure, which subsequently raises the temperatures in the compressor and condenser due to accelerated heat accumulation. This phenomenon aligns with the temperature increases observed in closed channels with restricted heat transfer [33].

Effect on water temperature: Regarding its impact on water temperature, the heat transfer from the refrigerant to the water is significantly hindered when utilizing coils with small diameters and minimal twists. This limitation reduces the surface contact area between the refrigerant and the water, leading to suboptimal heat absorption. As a result, the water temperature in the tank tends to be lower.

Helical coil diameter 25 cm (turn 10). Effect on compressors and condensers: This coil demonstrates improved performance compared to smaller coils, although it remains suboptimal for larger 2 PK systems. Nevertheless, it facilitates better temperature control in the compressor and condenser, thereby enhancing the system's overall efficiency. The larger diameter and increased circumference provide more space for the refrigerant to circulate, resulting in enhanced heat transfer and slightly more stable compressor pressure. While the temperature of the condenser remains elevated, it is less pronounced than in configurations utilizing smaller diameters [34].

Effect on water temperature: Regarding its impact on water temperature, this coil facilitates a more rapid increase in temperature compared to a 15 cm coil, although this effect is somewhat moderated by the larger system capacity. The increase in both turns and diameter enhances the surface area in contact with the water, thereby improving heat absorption and leading to a more significant rise in the water temperature within the tank.

Helical coil diameter 30 cm (15 turns). Effect on compressors and condensers: This coil is well-suited for 2 PK air conditioners as it efficiently accommodates larger refrigerant flows. By maintaining stable and lower temperatures in both the compressor and condenser, it enhances overall system efficiency and extends its lifespan. The increased diameter and additional turns of the coil promote more uniform heat distribution, thereby minimizing the risk of overheating in the compressor and condenser. This improvement is achieved through enhanced pressure distribution within the system [35].

Effect on water temperature: Regarding its impact on water temperature, the coil's larger surface area and multiple turns enhance the efficiency of heat transfer to the water in the tank, leading to a more rapid increase in water temperature. This configuration optimizes heat absorption due to its ample contact area, enabling the water temperature in the tank to reach higher levels compared to the previous two configurations.

The helical coil with a diameter of 30 cm and 15 turns exhibits the highest heat transfer efficiency, as evidenced by the elevated water temperature and reduced heating time. This improved efficiency can be attributed to two primary factors: an increased surface area for heat transfer and an extended contact time between the water and the heating pipe. The larger diameter enables a greater volume of water to be heated simultaneously, resulting in more uniform and rapid heating. Furthermore, the 15 turns create a longer flow path for the water, thereby enhancing the duration of contact with the heating pipe. This prolonged interaction significantly improves heat transfer effectiveness. These findings are consistent with prior research that emphasizes the influence of varying diameters and pitches of helical coils on heat transfer characteristics and pressure drops in air conditioning systems [36, 37].

The design of the helical coil significantly influences the temperatures of both the compressor and condenser. A helical coil with a diameter of 30 cm and 15 turns not only enhances the water temperature but also maintains optimal operating temperatures for the compressor and condenser. This efficiency in heat transfer reduces the workload on these components, allowing the compressor to operate less intensively to achieve the desired temperature. Consequently, this can extend the lifespan of the compressor and lower overall energy consumption. The condenser benefits as well, as it can release heat more effectively through a larger helical coil with multiple turns.

In comparison to helical coils with smaller diameters and fewer turns, those with a diameter of 30 cm and 15 turns demonstrate significant improvements in heat transfer efficiency. For instance, a helical coil with a diameter of 20 cm and 10 turns exhibits lower efficiency due to its reduced surface area and shorter contact time between the water and the heating pipe, resulting in prolonged heating times and lower water temperatures. Similarly, while a helical coil with a diameter of 25 cm and 10 turns shows improved efficiency over a coil with a diameter of 15 cm and 5 turns, it still falls short of the performance achieved with a coil of 30 cm in diameter and 15 turns.

The effects of variations in helical coil configurations on air conditioners with capacities of 1/2 PK and 1 PK mirror those observed in larger systems, such as 2 PK models. However, the intensity of these effects differs, with a more pronounced influence observed in higher-capacity systems. Conversely, air conditioners with smaller capacities exhibit a more limited impact, while larger systems can leverage variations in helical coil design more effectively to enhance heat transfer and overall system efficiency.

Each variation of the helical coil exerts a distinct impact based on the air conditioner’s capacity. In general:

15 cm diameter (5 turns): This configuration is effective for smaller systems, such as 1/2 PK air conditioners, but is less optimal for larger capacities.

25 cm diameter (10 turns): This design provides balanced performance across various air conditioning capacities, demonstrating its highest effectiveness in 1 PK air conditioners.

30 cm diameter (15 turns): This configuration is highly effective for larger air conditioning systems, particularly those rated at 2 PK, resulting in optimal heat transfer and enhanced efficiency.

The selection of coil configuration should be tailored to the specific capacity of the system to achieve maximum heat transfer efficiency, maintain optimal operating temperatures, and ensure the long-term stability of critical components, such as compressors and condensers.

The results of this study provide new insights into the optimization of heat recovery from split AC systems using helical coil configurations for water heating applications. These findings can be further understood by comparing them with existing studies in the field of energy recovery and HVAC systems. The results of this study provide new insights into the optimization of heat recovery from split AC systems using helical coil configurations for water heating applications. These findings can be further understood by comparing them with existing studies in the field of energy recovery and HVAC systems.

Previous studies have demonstrated that the design of helical coils plays a crucial role in improving heat transfer efficiency. For instance, Ye and Li [19] found that variable pitch on condenser coils significantly enhances the heat transfer coefficient, which aligns with our observation that a larger coil diameter and increased number of turns (30 cm, 15 turns) achieved higher water temperatures in less time. This is also consistent with findings from Bai et al. [11], who reported that increasing the number of coil rows and optimizing tube spacing improves heat transfer in air conditioning systems.

One notable difference between our study and some previous research is the magnitude of heat transfer efficiency achieved in relation to AC power capacity. While Singh et al. [8] reported a system COP of 4.03 using waste heat from refrigeration systems, the present study achieved a maximum water temperature of 57.72°C using a 2 PK split AC with a large-diameter coil. This suggests that variations in coil configuration, combined with split AC power capacity, can yield significantly different efficiency outcomes depending on system design.

Sharma et al. [10] demonstrated that applying advanced nanostructured coatings to coil surfaces could further enhance heat transfer rates. Though this study did not explore coil coatings, future research could investigate whether the application of such technologies might further improve the thermal performance of helical coils in split AC water heating systems.

A potential explanation for the discrepancies in results, particularly with regard to the heat transfer rate in smaller diameter coils (e.g., 15 cm, 5 turns), may be due to limitations in surface contact between the refrigerant and the water, as suggested by Ji et al. [36]. Smaller coils may not provide sufficient surface area for effective heat exchange, resulting in lower overall efficiency. This underscores the importance of coil size and design in maximizing the energy recovery potential from split AC systems.

The findings from this research have significant implications for the development of more energy-efficient HVAC systems, particularly for residential and commercial applications. By optimizing helical coil configurations and selecting appropriate AC power capacities, it is possible to enhance water heating efficiency while reducing operational costs and energy consumption. This is especially relevant for regions with high cooling demand, where waste heat from air conditioning systems can be repurposed to provide an additional energy-saving solution.

Furthermore, the ability to achieve rapid stabilization times and high water temperatures with larger coil diameters suggests that this technology could be integrated into sustainable building designs that prioritize energy conservation. Policymakers and engineers may leverage these findings to support energy and environmental policies that promote the use of split AC-based water heating systems in buildings, contributing to overall reductions in carbon emissions.

In conclusion, this study highlights the potential for optimizing coil configurations in split AC systems to improve heat recovery efficiency. Future research could explore the integration of advanced coil materials or coatings, as well as expand the analysis to include additional environmental factors that may influence system performance.

4. CONCLUSIONS

This study demonstrates the significant influence of AC power capacity and helical coil configurations on the efficiency of water heating systems using split air conditioners. The results highlight that increasing the diameter and number of turns in the helical coil, combined with higher AC power capacity, significantly improves water heating performance. Specifically, the system with a 30 cm coil and 15 turns, powered by a 2 PK AC unit, achieved the highest water temperature (57.72°C) and the fastest stabilization time (105 minutes). This underscores the importance of optimizing coil design to enhance heat transfer efficiency.

From a practical standpoint, these findings can be applied to improve energy efficiency in residential and commercial water heating systems by utilizing waste heat from split AC systems. The optimized configuration can reduce energy consumption and operational costs, making it an attractive option for sustainable building designs.

Future research could focus on integrating advanced materials or coatings for helical coils to further enhance heat transfer efficiency. Additionally, studies could explore the effects of varying environmental conditions, such as ambient temperature and humidity, on system performance, and evaluate the long-term durability of the optimized configurations in real-world applications. This research also opens opportunities for the development of multifunctional HVAC systems that integrate both cooling and heating solutions using waste heat recovery.

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NOMENCLATURE

T1	compressor temperature (°C)
T2	condenser temperature (°C)
Tw	water temperature (°C)

Abbreviations

AC	air conditioner
HVAC	heating, ventilation, and air conditioning
PK	paardekracht (horse power)