International Journal of Innovation in
Mechanical Engineering and Advanced Materials
Vol. 6 (No. 2), 2024, pp. 101-106
Journal homepage: publikasi.mercubuana.ac.id/index.php/ijimeam
DOI: 10.22441/ijimeam.v6i2.23744

Condensate Water Processing of Split-Unit Air Conditioning System on Commercial Building

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Abstract

This research investigates the feasibility and potential for water recovery from condensate produced by a split-unit air conditioning (AC) system in a commercial building, focusing on Scholar's Inn UTM (SIUTM) in Johor, Malaysia. The study involves the collection and measurement of condensate water from 243 AC units under various operational conditions. The results indicate that the building can produce up to 4,781 liters of condensate per day, amounting to an annual total of approximately 1,721,160 liters. This significant volume highlights the potential for utilizing condensate as an alternative water source, especially in regions with similar hot and humid climates. Water quality analysis was conducted to evaluate the suitability of the condensate for various applications. The condensate water exhibited a pH of 7.17, Total Dissolved Solids (TDS) of 1.0 mg/L, and a copper (Cu) concentration of 1.1 mg/L. While these parameters indicate that the water is within acceptable ranges for non-potable uses, such as irrigation or cooling tower makeup water, the copper concentration slightly exceeds the standard for potable water, necessitating treatment such as reverse osmosis before consumption. The study's findings underscore the environmental and economic benefits of condensate recovery, offering a sustainable solution to water scarcity issues in commercial buildings. By integrating condensate recovery systems, facilities can reduce their reliance on traditional water sources, contributing to broader water conservation efforts. Future research should explore the long-term viability and scalability of such systems in various building types and climates.

Article Info:
Received: 19 October 2023
Revised: 3 September 2024
Accepted: 9 September 2024
Available online: 15 September 2024

Keywords:
Condensate water recovery; split-unit air conditioning; water conservation; sustainability; water quality analysis

1. Introduction

Air conditioning has become an essential component of building ventilation, particularly in commercial settings like offices, malls, and shopping centers, which often rely on central systems. The study of condensate water recovery has gained attention only recently, driven by the growing global emphasis on sustainability. Natsu noted that condensate water has traditionally been overlooked as a freshwater source due to quality concerns, but it has now garnered interest for both drinkable and non-drinkable uses in response to water shortages [1]. Additionally, research into water recovery aims to enhance the coefficient of performance (COP) of air conditioning systems, leading to increased operational cost savings [1], [2].

Scholar's Inn at Universiti Teknologi Malaysia (SIUTM) is an apartment-style building that provides on-campus lodging for UTM students, staff, and visitors. The building uses a split-unit air conditioning system for space ventilation, which, like other similar installations, includes a condensate drainage system. However, improper piping installations can lead to issues such as disrupting pedestrian pathways, causing leaks, and promoting moss growth, all of which detract from the building's aesthetics and comfort. Economically, allowing condensate water to drain away is wasteful. This problem prompted the design of a storage tank system to recover and repurpose condensate water from the split-unit air conditioning system.

To measure the amount of condensate produced, several methods can be employed, including direct collection and analytical modeling based on the system's cooling capacity. Al-Farayedhi et al. [3] conducted a study comparing analytical and experimental methods to assess condensate as a water source in hot and humid regions, focusing on the relationship between relative humidity,

How to cite:

H. Nasution and N.H. Aubaidellah, "Condensate water processing of split-unit air conditioning system on commercial building," *Int. J. Innov. Mech. Eng. Adv. Mater*, vol. 6, no. 2, pp. 1-10, 2024

environmental temperature, and the volume of condensate produced. Barreira et al. conducted a thermoeconomic analysis of residential split-type air conditioners, finding that improvements in COP are directly correlated with increased cost savings [2]. One way to enhance COP is by reusing condensate within the system, which is often wasted in hot and humid climates. This highlights the importance of exploring the potential for water and energy sustainability through condensate recovery [4].

Condensate recovery involves repurposing the water and heat contained in condensate rather than discarding it, leading to significant savings in energy, chemical treatment, and make-up water [2], [5]. According to [5], condensate water is nearly identical to distilled water, with low mineral content and near-zero Total Dissolved Solids (TDS), making it suitable for various applications depending on the volume produced.

Research indicates that condensate water can have remarkably high quality, with conductivity levels as low as 18 μS/cm and turbidity around 0.041 NTU, comparable to distilled water [6]. This quality is due to the condensation process, which captures humidity from the air on cool surfaces within the air conditioning system, particularly the evaporator section [7]. The use of condensate water has the potential to significantly alleviate water scarcity, particularly in regions with severe shortages [8]–[10]. It can also be utilized effectively in applications such as serving as a cooling medium in HVAC systems, thereby improving the efficiency of air conditioning units [11], [12]. Integrating condensate water into cooling systems enhances energy efficiency and supports sustainable water management practices [13]. The feasibility of using condensate water for decentralized applications has also been explored, emphasizing its year-round availability and the potential to recover millions of liters of clean water daily [14], [15]. Recycling condensate water can reduce reliance on traditional water sources, promote sustainability, and align with global initiatives to address water scarcity and strengthen urban water system resilience [6], [10].

This research aims to evaluate the potential of condensate water recovery from split-unit air conditioning systems in commercial buildings, with a focus on Scholar's Inn UTM (SIUTM). The study investigates the volume of condensate produced and assesses its quality by measuring pH, TDS, and copper concentrations. These parameters are compared against raw water and drinking water standards to determine the condensate's suitability for various uses, including potable water after appropriate treatment. The research also seeks to contribute to water conservation efforts in hot and humid climates by exploring the potential applications of recovered condensate water.

2. Methods

The fundamental approach to obtaining condensate from the split-unit air conditioner involves direct collection of the water produced. The experimental setup involved maintaining the conditioned room at a steady temperature of 23°C, with condensate measurements taken every four hours. The average hourly condensate production was calculated by accounting for variables such as relative humidity and outdoor temperature. To determine the required capacity of the water storage tank, the maximum condensate production was estimated based on the building's annual occupancy rates. This calculated daily condensate volume serves as the basis for designing the water storage system, ensuring it can accommodate the peak production.

The total daily volume of condensate water is calculated to establish the necessary capacity for the storage tank. The volume of condensate produced is defined as the following equations.

Average condensate produced (Q_1) in one hour (L/hour) for one unit can be obtained by summing the volume of condensate water (V_H) in Liter:

$$Q_1 = \frac{(\sum V_H)}{4} \tag{1}$$

Total volume of condensate water per month (L/month) or V_M can be obtained by using the following equation:

$$V_M = Q_1 \times N \times 12 \times 30 \tag{2}$$

While total volume of condensate water per year (L/year) or V_Y can be obtained by using the following equation:

$$V_Y = Q_1 \times N \times 12 \times 365 \tag{3}$$

where N is number of split air conditioning unit in the building, 4 is hours of readings taken in a day, 12 is number of operation hours per day, 30 is number of days per month and 365 is number of days per year.

To design the appropriate water storage tank for condensate collection, several critical factors must be considered, including the tank's capacity, the materials used, its position, and the piping system configuration. The storage tank was specifically designed to hold the total volume of condensate generated by all units, with its capacity determined based on the maximum expected daily output. This ensures that the tank can accommodate the condensate without risk of overflow. The piping system is installed at an inclined angle to allow the condensate to flow into the tank by gravitational force alone (Figure 1), eliminating the need for a pump, except for one that might be installed in conjunction with the tank for specific tasks.

Water quality tests were conducted to evaluate the potential applications of the condensate, such as drinking water, raw water sources, or irrigation. A random sample of condensate was analyzed in the Chemical Analysis Laboratory of the Faculty of Science at UTM. Due to certain limitations, only three parameters were tested: pH, Total Dissolved Solids (TDS), and copper (Cu) content. These parameters are crucial, as pH indicates the water's acidity level, TDS reflects the mineral content, and Cu content determines whether any copper particles, potentially from the cooling coil, have contaminated the water.

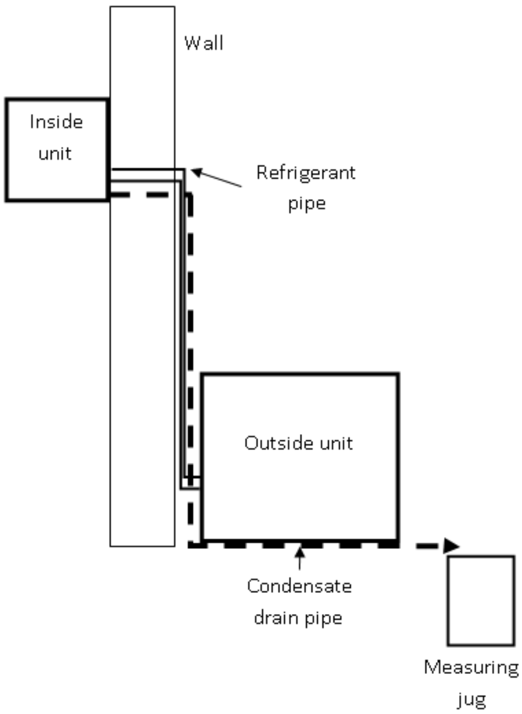

Figure 1. Experimental set up diagram

The experiment was conducted over several days, with measurements taken at specific intervals to capture variations in condensate production due to changes in ambient temperature and relative humidity. The air conditioning units were operated under controlled conditions, maintaining a room temperature of 23°C, with condensate collected every four hours. The condensate volume was recorded and averaged to determine the hourly production rate. Additionally, water quality tests were conducted in a certified laboratory, where pH, TDS, and copper levels were analyzed following standard procedures. The results were compared against regulatory standards to assess the condensate's suitability for various applications.

3. Results and Discussion

The experiment was done from 2.00 PM to 4.00 PM and 4.00 PM to 6.00 PM where it stated the highest temperature of the day with average high temperature of 31˚C. For actual low temperature, it usually happens during the night where the average low temperature is 24˚C. Noted that during day and night the ambient temperature is different where at night, the ambient temperature is colder and lower than during the day thus the room temperature will also differ during the night. The lowest relative humidity ranges from 50 to 70% and highest which ranges from 74% up to 94%. Both relative humidity and temperature affect the volume of condensate water produced by the split-unit air conditioner.

Most of the occupants of SIUTM usually stay in the room during the night where they will operate the air conditioning unit. The experiment on collecting the condensate volume is however conducted during the day due to some restriction. Thus, the value of the results should be slightly different. The average volume of condensate produced per hour for 1.5 HP is 2.5 L/hour whereas for 1 HP is 2.2 L/hour. These results can be said as the minimum condensate volume produced by the air conditioner since the condition is high temperature and low relative humidity that slow the condensation process outside the cooling coil.

In SIUTM, there are total of 93 rooms where 81 of them are air–conditioned and 12 without air-conditioner. In one room there will be three units of air-conditioners; two of them are 1 HP and one 1.5 HP. Thus, the total 1.5 HP air-conditioners in the building are 81 units and the total 1 HP air-conditioners in the building are 162 units. Equation 2 and 3 is used to determine the monthly and yearly production rate of the condensate water (Table 1).

Table 1. Condensate water prediction

AC Type (HP)	No. of Rooms	Day (L)	Month (L)	Year (L)
1.5	81	2,430	72,900	886,950
1	162	4,276.8	128,304	1,773,900
Total of condensate water		6,706.8	201,204	2,660,850

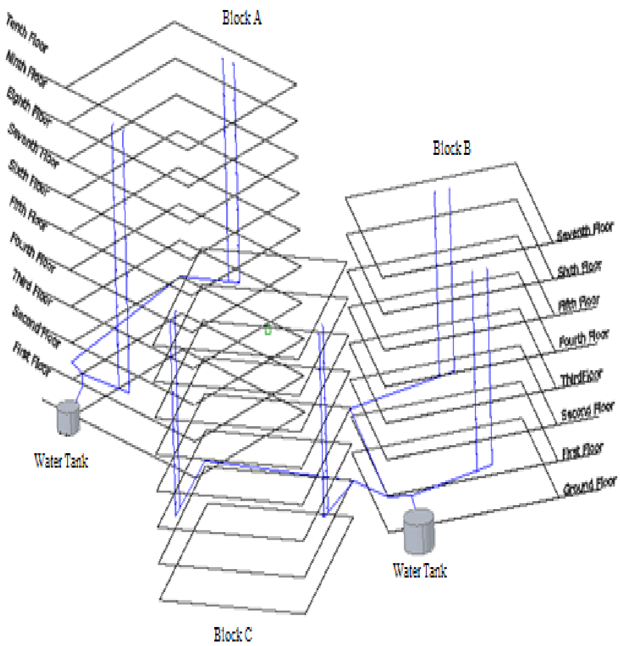

Figure 2. Piping and storage tank

The piping system is designed to efficiently direct condensate water from the split-unit air conditioners to the storage tanks. In the SIUTM building, 243 split-unit air conditioners are installed across various levels. The existing condensate drainpipes currently direct the water to external drains. To collect all the condensate, the existing pipes will be interconnected using additional pipe junctions, allowing the condensate to converge into a single, larger pipe before entering the storage tanks. It is crucial that the condensate water flows smoothly through the drainpipes to prevent backflow and potential leaks within the units. Therefore, the pipes will be arranged at an incline, utilizing gravitational force to guide the water downward. Figure 2 illustrates the piping system that needs to be installed and integrated with the current drainpipes. This setup will ensure that condensate water from all the split-unit compressors is funneled into a single pipe, which then directs the water into the storage tank located on the ground level. The inclination of the pipe is essential to harness gravitational force, eliminating the need for a pump to collect the water.

Table 2. Condensate water quality

Parameter	Condensate Water Quality	Recommended Raw Water Quality	Drinking Water Quality Standards
		Acceptable value	Maximum acceptable value
pH	7.17	5.5-9.0	6.5-9.0
TDS	1.0 mg/litre	1500 mg/litre	1000 mg/litre
Cu	1.1 mg/litre	1.0 mg/litre	1.0 mg/litre

Table 2 shows that the condensate water has a pH value of 7.17, which falls within the acceptable range for both raw water and drinking water quality standards set by the Ministry of Health Malaysia. The pH value indicates whether the water is acidic or alkaline; in this case, it is within an acceptable range. Total Dissolved Solids (TDS) consist of dissolved inorganic salts and small amounts of organic matter in the water. The results indicate that the TDS value is 1.0 mg/L, which is significantly below the drinking water standard of 1000 mg/L set by the Ministry of Health Malaysia. This extremely low TDS level, close to zero, means that the water is mineral-free, making it corrosive to most metals, particularly steel and iron [5]. At higher TDS levels, issues such as unpalatability, mineral deposition, excessive hardness, and corrosion may occur.

Regarding copper (Cu) content, the measured concentration is 1.055 mg/L, slightly exceeding the Ministry of Health Malaysia's standard of 1.0 mg/L for both raw and drinking water. At this concentration, the water may cause staining and have a bitter taste, though the health concern threshold is 1.3 mg/L [16]. Therefore, while the condensate water can be used as a raw water source, it requires treatment to reduce the copper content if intended for drinking. Treatment options include reverse osmosis, distillation, or ion exchange. Previous studies by Natsu and others have shown that condensate water is similar to rainwater [1]. While condensate water is essentially distilled pure water, it may require further treatment to remove contaminants that could accumulate during the condensation process, particularly heavy metals from contact with the copper cooling coils and other air conditioning components [17].

The slightly elevated copper concentration in the condensate, measured at 1.1 mg/L, suggests that the solubility of copper ions is influenced by the slightly acidic conditions typically found in condensate water. The solubility of copper is affected by both the pH level and the temperature at which condensation occurs. Since copper can leach from the components of the air conditioning system, it is essential to treat the water if it is intended for potable use. Methods such as reverse osmosis or ion exchange are recommended to reduce the copper concentration to safe levels.

4. Conclusions

The volume of condensate water produced by the SIUTM building's split-unit air conditioning system is substantial and represents a valuable resource that should not be wasted. Water quality tests indicate that the collected condensate is comparable to distilled water, making it suitable for non-potable uses such as plant irrigation, car washing, and floor cleaning. However, for the condensate to be safe for drinking, treatment processes are necessary to reduce or eliminate copper contaminants. The recovery of condensate water at SIUTM is both environmentally and economically beneficial, and the appropriate design of water storage tanks has already been proposed to maximize this resource. This study confirms that significant volumes of condensate water can be effectively recovered from split-unit air conditioning systems, presenting a viable alternative water source for non-potable applications. While the quality of the condensate is adequate for many uses, it does require treatment to reduce copper concentrations to safe levels for potable use. This research adds to the growing body of evidence that supports water recovery as a sustainable practice in building management, especially in humid regions. Future research should focus on assessing the long-term viability of using condensate water across different applications and exploring cost-effective treatment methods for making the water suitable for drinking.

Acknowledgements

This work was supported by the Ministry of Education Malaysia under the Knowledge Transfer Program (R.J130000.7809.4L509) and the Automotive Development Center (ADC), Universiti Teknologi Malaysia. The authors gratefully acknowledge this support.

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