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Harvesting condensate wastewater from commercial buildings air handling unit (AHU) drainage: An opportunity for water conservation

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ABSTRACT

Water wastage is a matter of great concern, especially in this era of rapid development. Water consumption in high-rise and large-sized buildings is very high. Furthermore, high-rise buildings use a lot of water to generate the use of HVAC (Heating, Ventilation, and Air Conditioning) machines. However, the waste of water from this machine is also very disturbing. Therefore, it is important for us to realize that various ways and technologies can be used and utilized to prevent waste from happening. This research focuses on the wastage of water and waste water from air handling unit machines in high-rise commercial buildings around Penang, Malaysia. To make this study a success, several methods have been used, including interviews, observation at the study site, and conducting research through newspapers, journals, reports, and so on. Through this method, data to be analyzed can be collected. In this study, several factors lead to the waste of water from the Air Handling Unit machine, which will have adverse effects on the machine, the building, and also the environment such as condensate and drainage. To overcome the problem, it is important to implement proactive routine maintenance practices for the HVAC system to reduce the AHU wastewater. The finding incorporation of water-saving methods, such as using AHU wastewater for other non-potable purposes, is a practical and ecologically appropriate approach. This research emphasizes the potential for large water savings and environmental advantages in commercial buildings, calling for greater adoption of such methods in facility management and building operations.

1. Introduction

The Green Building Index (GBI) serves as a pivotal metric assessing a building's adherence to sustainable practices aimed at environmental preservation [1-4]. To attain recognition, buildings must fulfill criteria across seven key components, including environmentally friendly materials,

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energy efficiency, indoor air quality, water efficiency, waste reduction, smart growth sustainable development, and toxics reduction [6-8]. This study focuses on evaluating water efficiency in high-rise buildings in Penang that have yet to achieve green building status [9]. Specifically, the researcher will investigate water conservation strategies concerning HVAC condensation and drainage, with a particular emphasis on Air Handling Units (AHUs). AHUs are extensively utilized in high-rise buildings due to their critical role in maintaining indoor environmental conditions amidst high occupancy rates and continuous operation from early morning to evening [10]. The study aims to assess the feasibility of reclaiming and reusing water from AHU condensation and drainage, contributing valuable insights into sustainable water management practices for commercial buildings.

Population growth significantly impacts a country's water supply [11], as increased population leads to higher water demand for daily consumption and various activities such as car washing, irrigation, and mechanical systems like Air Handling Units (AHUs). Effective management of rainwater through catchment systems or reservoir operations is crucial for augmenting water resources. In Penang, efforts since 1999 by the State Government and PBAPP have focused on raising awareness and promoting water conservation due to limited air pressure and raw water availability [12]. This paper aims to introduce the forthcoming thesis on AHU wastewater conservation, underscoring the necessity for proactive measures in building technologies and development practices to maximize the benefits of water conservation in modern urban contexts.

2. Literature review

Faults in building HVAC systems, encompassing design flaws, equipment malfunctions, and control system errors, pose significant risks of water wastage [13]. These faults, ranging from stuck dampers and leaking valves to sensor biases and operational inefficiencies, contribute to increased water consumption if not promptly detected and rectified. Categorized into degradation faults that worsen gradually and abrupt faults that occur suddenly, these issues undermine water conservation efforts in high-rise buildings.

Air leakage from Air-Handling Units (AHUs), a subset of duct leakage concerns, is critical for indoor air quality (IAQ) and energy efficiency [14]. Addressing these issues through duct sealing and insulation not only enhances IAQ and reduces energy consumption but also mitigates water waste by preventing moisture buildup and condensation. This integrated approach to improving HVAC system efficiency underscores the importance of holistic strategies for creating sustainable and healthy indoor environments in buildings.

2.1 Water Consumption in High-Rise Buildings

High-rise buildings are buildings that use a lot of water compared to other one-story buildings. This is because high-rise buildings have more rooms and accommodate a large number of users. One of the reasons why the amount of water used in high-rise buildings is high is because of the large number of users and also the number of items that require water to operate said [15]. According to Rajkumar and Nielsen [16] among the uses of water in high-rise buildings are toilets, janitor closets and kitchens, plumbing, mechanical systems, maintenance, irrigation and outdoor use, laboratory and building equipment use, and many more.

The building's water tank will distribute water to each floor of the building for various uses. The bigger the building, the more users can fill the space [17]. The more users there are, the more water is used in one building. This includes the use of mechanical systems that use water for building management. The use of many mechanical systems in the building is to ensure that the operation of the building can run smoothly in line with its purpose, in addition to providing comfort to users.

2.2 Heating, Ventilation and Air Conditioning

HVAC systems play an important role in buildings by facilitating the exchange of indoor air with fresh, cooled air to maintain comfort and air quality. This process involves the removal of hot air and its replacement with cooler, fresher air, enhancing indoor environmental conditions. In specific applications, such as fire smoke control, HVAC systems may incorporate specialized features to manage smoke in emergencies [18]. Despite the extensive research conducted in the field of HVAC systems [19], its scope remains vast and complex, reflecting its pivotal role in building operations and occupant comfort.

HVAC, commonly referred to as a package unit, encompasses various subsystems and configurations, often serving as a central system within buildings [18]. It functions both as a local and central system, depending on architectural considerations, as delineated in previous studies [20]. The distinction between central and local HVAC systems hinges on their integration within building designs. This analysis emphasizes the active functionalities and structural components tailored to meet specific building requirements within the HVAC framework.

The design and operation of HVAC systems are meticulously tailored to achieve distinct objectives within building environments [20]. Central HVAC systems encompass several classifications, including All-Air Systems, All-Water Systems, Air-Water Systems, Water-Source Heat Pumps, and Heating and Cooling Panels, each designed for specific heating, cooling, and ventilation functions. Conversely, local HVAC systems are categorized into Local Heating Systems, Local Cooling Systems, Local Ventilation Systems, Local Air-Conditioning Systems, and Split Systems, providing targeted climate control solutions within smaller, localized spaces. These classifications underscore the diversity and specialized applications of HVAC technologies in building infrastructure.

2.3 Air Handling Unit

According to Lun [14] AHU functions as a control unit to treat clean air and provide fresh air into a room. This is so that users are always in a comfortable state that is not too hot or too cold and can breathe clean and quality air even if they are inside the building. AHU functions as a unit that treats, transmits, filters, recovers, heats, cools, humidifies, and dehumidifies air. Dual duct air handling unit components are a damper, filters, supply fan, cooling coil, heating coil, humidifier, mixing box, diffuser, outside air, and return air. Because the use of HVAC is very important in a high-rise building, the use of chiller systems between systems that use water as the main source of cold air supply into the building space through AHU [21]. The water used to provide cool air is always recycled. But at the same time, there is wastewater from this chiller system.

2.4 Wastewater in AHU

2.4.1 Condensate

Mentioned by Fernandez [22] that air leakage can be through a drain. These drains are typically found in cooling coils or other areas where condensation may happen. However, Licina and Sekhar [23] once mention that hot and humid climates and latent load are possible to produce a large amount of condensate over time. Within temperate climates, the amount of latent load can change over time and produce a variable amount of condensate. [24] Eades adding when the cooling coil dew point temperature is lower than the dew point temperature of the ambient, during the cooling and dehumidification the condensate will be processed. From SkillCat [25], a drain pan will hold the water that drops from the cooling point and the condensate drain line will remove the water from the drain pan to a sewerage pipe. According to Professional Services [26] condensation on air ducts is one of the most consistent causes of possible water damage. Once the cold of your air conditioning ducting is connected with the warm air from the outside, it will procedure sweating in the air ducts. Extra condensation will build up on your air ducts, the colder your air conditioner will be. Wooten [27] and Wmr [28] mentioned once said that when AHU is running, the condensate will cause the water will come out from the floor drain. A larger use of AHU will produce a large amount of condensate that can be collected and reused. All excess water from condensate and sweating will be delivered to the sewage system or Septic Tank Effluent Drainage System (STEDS) [29].

2.4.2 Water leaks

According to Frimec [30] water leakage from the air handling unit is due to the blower speed being too high, and condensing water cannot be discharged freely to the drain pipe. The water flows out from the drain pan. Eades [24] mentioned that faulty and damaged pipes, valves, or connections can cause water leaks, leading to moisture accumulation and potential damage to the AHU. Torsten [31] added, water accumulation in or around the AHU is a risk concern that can cause system damage and the formation of mold. Possible causes include problems with the cooling coil, broken pumps, and clogged condensate drains.

3. Methodology

The research began with an overview of high-rise commercial buildings in Penang and problems related to the building's AHU machines regarding wastewater and condensation. This chapter presents the methods that will be used to identify problems related to AHU machines and the main strategies to solve those problems. Before the method is carried out, the identification of the study location needs to be carried out. Table 1 shows the research questions, objectives, methods and strategies for the studies.

Table 1
Research questions, objectives, methods and strategies for the studies

Research question	Research objectives	Research Methods	Research strategies/ methods
What is the factor that leads to sweating, condensation, water leaking, and drainage on the Air Handling Unit system in high-rise buildings?	To identify the factors of sweating, condensation, water leak, and drainage on the AHU in high-rise buildings.	Case Study	Observation
How to prevent the problem of sweating, condensation, water leaking, and drainage on the Air Handling Unit system in high-rise buildings from continuing?	To examine key strategies that can be implemented to reduce the problem of sweating, condensation, water leaking, and drainage on the Air Handling Unit system in High-rise buildings from continuing.	Interview	Thematic analysis
What kind of recommendation for water conservation for Air Handling Unit system water problems such as sweating, condensation, water leaks, and drainage in high-rise buildings can be applied?	To recommend water conservation for Air Handling Unit system water problems such as sweating, condensation, water leaks, and drainage in high-rise buildings.	Interview	Thematic analysis

3.1 Case Studies

This study examines the operational dynamics of Air Handling Units (AHUs) in high-rise commercial buildings during typical working hours (8:00 AM to 5:00 PM). The selected buildings meet three criteria: they utilize AHUs for HVAC systems, are classified as high-rise structures, and hold commercial status. These criteria ensure the study's focus on AHU usage patterns under peak operational conditions, providing insights into energy consumption, operational efficiencies, and environmental impacts associated with AHU use in multi-tenant, high-rise environments. By concentrating on AHU performance during business hours, the research aims to inform strategies for optimizing wastewater from AHU units and promoting sustainable building management practices in this sector, contributing valuable empirical data to enhance environmental sustainability in high-rise commercial buildings. Table 2 summarizes the case studies type.

Table 2
Case study description

Case Study	Case Study A	Case Study B	Case Study C
Location	No. X, Jalan Sultan Ahmad Shah, Georgetown, Penang	No. Y, Jalan Sultan Ahmad Shah, Georgetown, Penang	No. Z, Jalan Sultan Ahmad Shah, Georgetown, Penang
Age	>10 years	>10 years	>10 years
Storey	30	23	22
Status	Commercial office building	Commercial office building	Commercial office building

Fig. 1. Condensation in air handling unit

From the observation of all three selected case studies, Fig. 1 shows the condensation that happens in the Air Handling Unit. According to Wilcox [32] frozen evaporator coil will cause wastewater in AHU. A clogged air filter and low refrigerant levels are the most common cause of evaporator coil freezing. The temperature level surrounding the coils in an undercharged HVAC unit may drop below freezing point. Ice will start to develop when the warm air from temperature-controlled areas circulates through the system and freezes the moisture that is collected on the evaporator coil. The ice began to melt as soon the HVAC unit turned off and the ensuing water will overflow the drain pan and may have trickled out of the ceiling vents. Professional Services [26] mentioned, that the condensation on the air ducts will increase as the room humidity rises. This specifically occurs when running the air conditioner. If the outside temperature is reduced with excessive humidity, it will cause expansion and sweating on the AHU surface. The AHU unit is not sweating when the outside room temperature is 27°C and the relative humidity is 90% [33].

Fig. 2. Water leaking from air handling unit

From the observation, Fig. 2 shows water leaking from the air handling unit system. According to Wilcox [32] written that the faulty condensate pump will cause a water leakage. Approximately HVAC systems include a condensate drain pump, which removes the water resultant after the dehumidification and condensation processes from the building. When the pump breaks down, the water cannot be pumped outside and it will be clogged and will be flooded and overflow. Wilcox [32] also added the clogged condensate drain line causing a problem of water leaks. When the drain pipe fills with dust, dirt, rust, and other material and the drain pan overflows, it will cause a water leak in AHU. When condensed moisture builds up inside the duct system and around the vent due to its inability to empty down the drain pipe, the water will begin to leak out. Another common fault that can lead to freeze-ups and water leaks from the unit is the oversized size of the unit system. This is because a large unit size is more prone to severe temperature swings, insufficient dehumidification, and short cycling [32].

3.2 Interview

An interview session was integral to the success of this research study, involving the management of the selected case study building to gather insights into the challenges encountered in Air Handling Unit (AHU) operations and the strategies employed to address them. Two key personnel from each building, namely the facilities manager and maintenance team leader, were interviewed. Additionally, six experts representing various professions including green building experts, building developers, contractors, and engineers were consulted to obtain their perspectives on water conservation in alignment with green building standards. This comprehensive approach aimed to collect firsthand information on AHU-related issues and gather expert opinions on sustainable water management practices, enriching the study with diverse insights from both operational and technical perspectives. Tables 2 and 3 summarized the demographic of respondents for objective B and C, respectively.

Table 3
Demographic of respondent for objective B

Case Study	Case Study A	Case Study B	Case Study C
Demographic	Mr. A	Mr. B	Mr. C
Position	Facilities manager	Facilities manager	Executive M&E
Working experience	15 years	9 years	12 years

Table 4. Demographic of respondent for objective C

Demographic	Position	Working experience
Mr. GBE	Green Building Expert	14
Mr. LA	Local Authorities	17
Mr. BT	Building Technologists	25
Mr. EH	Engineer (HVAC env.)	13
Mr. BD	Building Developer	7
Mr. CT	Contractor	9

4. Results and discussion

4.1 Factors of Sweating, Condensation, Water Leak, and Drainage on Ahu in High-Rise Buildings

This research emphasizes the crucial importance of collecting wastewater and condensation from Air Handling Units (AHUs) in high-rise buildings, with a focus on identifying and managing concerns such as sweating, condensation, water leaks, and drainage difficulties impacting chillers and AHUs. The article emphasizes the limitations of using only visual observation to measure wastewater, highlighting the need for systematic data-gathering methods. The study focuses on three buildings to collect empirical data on the average amount of wastewater collected by AHUs, to provide a quantitative foundation for understanding and controlling water-related concerns in building HVAC systems. By using a systematic approach to data collecting, the study provides significant insights into operational efficiency and maintenance procedures that can improve AHU performance and building sustainability. Future study might build on these findings by investigating the relationships between wastewater quantities and environmental variables, outlining best practices for water management in high-rise building contexts. During the modelling step, observations throughout the normal operating conditions (NOC) of the Air Operating Unit system are used. The observational input consists of a record of all variables considered from those that have been collected during the day of data collection. Observations are arranged in rows containing as much data, as (d), as the number of variables, (j), times the number of samples in a day, (k), in other words, ($d = j \times k$).

4.1.1 Case study A

The test configuration for this experiment is shown in Table 5. The value of the amount of defective wastewater for the average day for continuous AHU operation is 5280 ℓ. This significant volume underscores the impact of having a high total number of AHUs within the building, specifically 63 units. The direct correlation observed between AHU usage and wastewater generation highlights the role of air conditioning systems in contributing to wastewater volumes, primarily due to condensation issues exacerbated by temperature fluctuations. These findings emphasize the need for effective management strategies to mitigate water wastage associated with HVAC operations in buildings. Future studies could delve deeper into seasonal variations and operational practices affecting wastewater production to refine sustainability measures and optimize water resource management in building environments.

Table 5
The value of wastewater collected for case study A

Description	Code	Data
Pail volume (ℓ)	α	15 ℓ
Time for a full pail	b	2 min
Number of AHU		63 unit
Total wastewater (ℓ/hour) [C = $\frac{a}{b}$ × 60]	j	480 ℓ
Operation hour (per day)	k	11 hours
Total wastewater (ℓ/day) [j × k]	d	5280 ℓ

4.1.2 Case Study B

Based on the findings presented in Table 6, the total volume of wastewater collected from the Air Handling Unit (AHU) system in the drainage system of the case study amounts to 3300 liters. This empirical data underscores the direct correlation between the number of AHUs installed in a building and the quantity of wastewater discharged. Case Study A, with 63 AHU units, produced a higher wastewater volume compared to Case Study B, which operated with 42 AHU units over the same 11-hour duration per working day. This observation substantiates that the quantity of AHUs significantly influences wastewater generation rates in buildings. Moreover, while both case studies operated for identical durations, variations in ambient temperature during the study period may also contribute to fluctuations in daily wastewater production. This analysis underscores the multifaceted factors affecting wastewater generation in building HVAC systems, highlighting the importance of comprehensive data collection and environmental conditions assessment in understanding and managing water-related challenges effectively. Further research could explore additional variables impacting wastewater production to refine strategies for optimizing AHU performance and water management practices in high-rise buildings.

Table 6
The value of wastewater collected for case study B

Description	Code	Data
Pail volume (ℓ)	α	15 ℓ
Time for a full pail	b	3 min
Number of AHU		42 unit
Total wastewater (ℓ/hour) [C = $\frac{a}{b}$ × 60]	j	300 ℓ
Operation hour (per day)	k	11 hours
Total wastewater (ℓ/day) [j × k]	d	3300 ℓ

4.1.3 Case study C

Based on the findings from the conducted research, as detailed in Table 7, the daily volume of wastewater amounts to 1650 liters, representing the lowest among the three examined buildings. This disparity can be attributed to the building's relatively low number of Air Handling Units (AHUs), totaling only 20 units compared to other case studies. Additionally, favorable weather conditions, characterized by clear skies and the absence of rainfall on the study day, contributed to minimal condensation issues stemming from temperature stability.

Furthermore, the extended duration of 6 minutes required to fill the collection bucket with AHU wastewater indicates a slower accumulation rate compared to the other case studies. These insights underscore the multifaceted influences of AHU quantity, environmental factors, and operational dynamics on wastewater generation in building HVAC systems, emphasizing the importance of contextual analysis in understanding and managing water-related challenges effectively. Future studies could explore additional variables impacting wastewater production to further refine strategies for optimizing AHU performance and water resource management practices in building environments.

Table 7
The value of wastewater collected for case study C

Description	Code	Data
Pail volume (ℓ)	α	15 ℓ
Time for a full pail	b	6 min
Number of AHU		20 unit
Total wastewater (ℓ/hour) [C = $\frac{a}{b}$ × 60]	j	150 ℓ
Operation hour (per day)	k	11 hours
Total wastewater (ℓ/day) [j × k]	d	1650 ℓ

A comparative investigation of wastewater collection from Air Handling Units (AHUs) throughout three case studies demonstrates various parameters impacting daily quantities. Case Study A, which had 63 AHU units, had the maximum daily wastewater production of 5380 liters, suggesting a clear relationship between AHU number and water generation. Case Study B, which operates 42 AHU units, reported 3300 liters per day, highlighting the importance of system scale in wastewater generation. Case Study C, with 20 AHU units, had the lowest daily output of 1650 liters, owing to fewer units and favorable weather conditions. These findings emphasize the importance of AHU amount and environmental factors in affecting wastewater quantities, emphasizing prospects for enhancing water management methods in HVAC system design to improve sustainability and operational efficiency.

4.2 Strategies to Reduce the Problem of Air Handling Unit System

The data was gained from the interview session that was conducted with three people in charge of each of the selected case study. Mr A, Mr. B, and Mr. C.

4.2.1 Current water practice in place for HVAC systems in high-rise buildings

The researcher learned from the interview that efficient water resource management in HVAC systems for high-rise buildings requires several strategic techniques. Water-efficient cooling towers use innovative technology such as variable frequency motors and efficient spray nozzles to improve cooling performance while reducing water use. According to Mr. B rainwater harvesting systems are increasingly being used to gather and reuse rainwater for non-potable applications like irrigation and toilet flushing, encouraging sustainability and lowering dependency on municipal water supplies. Water treatment and filtration procedures assure quality compliance through methods such as filtration, chemical treatment, and UV disinfection, which are critical for reducing system corrosion and extending operational life according to the interview session. Demand-based control systems improve water use by modifying it in real time depending on building occupancy and environmental conditions, reducing waste. Regarding Mr. A, proactive leak detection and repair procedures increase efficiency by quickly discovering and correcting leaks, reducing water loss, and protecting building structural integrity. These integrated techniques highlight a holistic approach to sustainable water management in high-rise building HVAC systems.

4.2.2 Strategies and technologies used to empower and improve the use of HVAC systems

Mr B. describes the strategies and technology utilized to improve HVAC systems, such as smart thermostats (e.g., Honeywell Thermostat) used in case study B. Other technologies employed in the selected case study include Building Automation Systems (BAS), sophisticated controls, and algorithms, all of which are significant in improving energy efficiency and operational effectiveness. Smart thermostats allow for exact temperature management and scheduling depending on occupancy patterns and external circumstances, which helps to save energy and improve user comfort. BAS integrates various building systems, including HVAC, to centrally monitor and manage operations, enabling real-time changes and preventative maintenance scheduling. Advanced controls and algorithms use data analytics and predictive modelling to further improve HVAC operations, dynamically adjusting system performance to changes in the environment and occupancy needs. These technologies enable building managers to achieve greater energy efficiency, lower operational costs, and higher indoor environmental quality, therefore promoting sustainable building practices and occupant happiness in a variety of building situations.

4.2.3 Challenges do facility managers face in implementing effective water conservation measures for HVAC systems, especially in high-rise structures

Facility managers have several problems when adopting efficient water conservation strategies for HVAC systems in high-rise buildings. Limited space makes it difficult to install extra equipment such as water tanks, water-efficient cooling towers, or rainwater harvesting systems, necessitating inventive design solutions to optimize use while maintaining building performance. Budget limits pose another important challenge, since early investments in sophisticated water-saving technology such as smart thermostats or BAS may be prohibitively expensive, demanding careful financial planning and project priority. The complexity of HVAC systems, along with the integration of many subsystems and modern controls, necessitates specialist knowledge for effective operation and maintenance. Older buildings have infrastructural restrictions, such as antiquated plumbing systems or insufficient room for adapting contemporary water conservation devices, which might impede implementation attempts. Water conservation measures must be maintained and monitored on an ongoing basis to ensure that systems work at optimal efficiency, with potential concerns such as leaks addressed as soon as possible to reduce water waste. To effectively adopt sustainable water management strategies in high-rise building contexts, it is necessary to take a strategic approach that includes technological feasibility, financial viability, and operational efficiency.

4.2.4 Specific guidelines or standards that facility managers need to adhere to in terms of usage for HVAC

According to the interviewee, facility managers who supervise HVAC systems must follow particular norms and regulations to guarantee compliance, efficiency, and safety. The ASHRAE

(American Society of Heating, Refrigerating, and Air-Conditioning Engineers) Standards give comprehensive guidelines on HVAC design, installation, and operation, to improve energy efficiency and indoor air quality. In addition, Building Performance Standards provide criteria for energy efficiency and sustainability, promoting the use of efficient HVAC technology and practices. Furthermore, Occupational Safety and Health Administration (OSHA) Regulations require workplace safety, including HVAC system maintenance and operating guidelines to protect staff from hazards such as electrical threats and air quality concerns. Local building codes and laws provide construction, installation, and operational requirements for specific geographic areas, assuring compliance with safety and environmental standards. Adhering to these criteria guarantees regulatory compliance, but also promotes optimal HVAC system performance, energy efficiency, occupant comfort, and environmental sustainability in building operations.

4.2.5 Routine maintenance practices of the HVAC system in high-rise building

Routine maintenance practices are important for maintaining the best performance and lifetime of HVAC systems in high-rise structures. From the interview session, regular filter change eliminates dust and debris buildup, which maintains indoor air quality and reduces system strain. Coil cleaning eliminates dirt and debris from evaporator and condenser coils, resulting in more effective heat transmission and lower energy use. Regular checking refrigerant levels reduces system inefficiencies and possible compressor damage owing to insufficient cooling capability. Inspecting and lubricating moving parts, such as fan motors and bearings, lowers friction and wear, increasing operating efficiency and longevity. Inspecting and calibrating controls assures proper system functioning and energy efficiency. Inspecting ductwork for leaks and obstructions helps to maintain airflow and reduce energy loss. Checking drains and condensate pipes helps to avoid water damage and microbial development. Inspecting exhaust fans and vents provides adequate ventilation and interior air quality. Last but not least, the interviewee will document and schedule maintenance chores to help manage upkeep efforts, assuring proactive maintenance and reducing unexpected breakdowns. Together, these approaches maximize HVAC system efficiency, minimize operational costs, and extend equipment lifespan in high-rise buildings.

4.3 Recommendations on water conservation for air handling unit system water problems such as sweating, condensation, water leaks, and drainage in high-rise buildings

All the information was obtained through the interview session that was carried out with six different qualified professionals.

4.3.1 Criteria related to water that need to be met for green building certification

In the field of sustainable architecture and construction, adhering to water management requirements is critical for obtaining green building certification. These criteria include various critical practices targeted at reducing water usage and increasing resource efficiency. According to the interviewee, rainwater harvesting is a critical component in which buildings gather and use rainfall for non-potable applications such as irrigation and toilet flushing, lowering demand for municipal water supply and limiting stormwater runoff. Similarly, water recycling systems serve an important role by processing greywater from sinks, showers, and laundry for reuse in jobs that do not require potable water, therefore preserving freshwater resources and reducing wastewater output. Furthermore, they added that good water-efficient irrigation and landscaping methods help sustainability efforts by using technology such as drip irrigation and native plant species, which minimize outdoor water use while increasing biodiversity. Indoors, installing water-efficient fittings like low-flow faucets and toilets reduces water waste while retaining functioning. Furthermore, combining metering systems and leak detection technologies allows for real-time monitoring of water usage trends as well as the prompt discovery of leaks, promoting proactive management and conservation. These thorough measures not only match green building certification criteria but also highlight the dedication to environmental stewardship and resource conservation in the built environment.

4.3.2 Educate about the importance of water conservation in HVAC systems problems such as sweating, condensation, water leaks, and drainage in high-rise buildings

Water conservation in HVAC (Heating, Ventilation, and Air Conditioning) systems in high-rise buildings is important for more than just environmental stewardship, it also has operational and economic advantages. Efficient water management is critical for preventing typical HVAC concerns including sweating, condensation, water leaks, and poor drainage, all of which can risk building integrity and occupant comfort. Maintenance is serious in tackling these concerns since frequent examination and upkeep of HVAC components prevent possible water-related problems before they worsen.

Identification and troubleshooting abilities are equally important, allowing for rapid discovery and correction of leaks or drainage inefficiencies that may otherwise lead to water waste and structural damage. Furthermore, incorporating water-saving technologies into HVAC systems not only improves performance but also promotes sustainability. Advanced cooling tower controls that optimize water usage based on real-time circumstances, as well as energy-efficient chillers that reduce water consumption, provide important contributions to conservation efforts. These advances not only decrease the environmental effect by decreasing water withdrawals and minimizing chemical treatment demands but also produce significant financial savings through reduced utility costs and maintenance expenditures.

From an environmental standpoint, efficient water conservation methods in HVAC systems reduce the demand for local water supplies and contribute to overall water sustainability in urban contexts. High-rise buildings may improve operational dependability and demonstrate a commitment to responsible resource management by prioritizing proactive maintenance, utilizing technology improvements, and incorporating effective troubleshooting processes. Thus, promoting awareness of the need for water conservation within HVAC systems highlights its many benefits, which include operational efficiency, environmental stewardship, and long-term cost savings in the built environment.

4.3.3 Technologies used for water conservation of air handling unit system problems

According to the respondent, incorporating innovative water conservation technology into air handling units (AHUs) is critical for improving sustainability and operating efficiency. Advanced water treatment technologies are critical in preserving water quality within AHUs, including methods such as filtration and disinfection to ensure maximum performance while reducing chemical consumption and environmental effects. Furthermore, smart water management systems and decentralized water solutions provide novel techniques for optimizing water consumption.

These systems use real-time data and IoT technology to monitor and alter water consumption based on demand and environmental conditions, lowering overall water consumption and boosting resource efficiency. Biological water treatment systems, hybrid cooling technologies, and the incorporation of greywater and rainfall all contribute to conservation efforts by providing long-term options that reduce freshwater demand while improving the ecological impact of building operations. Together, these solutions not only increase AHU performance and dependability but also highlight the significance of technical innovation in establishing sustainable water management practices in modern buildings.

4.3.4 Recommendation used for water conservation in HVAC systems problems such as sweating, condensation, water leaks, and drainage in high-rise buildings

In high-rise buildings, effective water conservation methods for HVAC systems, particularly air handling units (AHUs), are critical for long-term building management. Regarding the interviewee, one essential guideline is to maximize the use of non-potable water for activities such as toilet flushing, cleaning, and outdoor gardening. This strategy reduces the demand for freshwater resources while resolving condensation, water leaks, and drainage inefficiencies in AHUs. Furthermore, including water-saving fixtures and establishing regular maintenance routines for AHU drainage systems and condensate management are critical tasks. Proactive maintenance helps to reduce the dangers of water collection and structural damage, guaranteeing operational dependability and minimizing environmental effect. These solutions assist responsible water management in high-rise structures by encouraging efficiency, sustainability, and resilience in building operations.

5. Conclusions

This research focuses on water saving in HVAC systems, especially air handling units (AHUs) in high-rise buildings, and provides valuable insights into operational efficiency and sustainability. Empirical data show that AHU amount has a direct influence on daily wastewater creation by measuring wastewater quantities and resolving concerns including sweating, condensation, water leaks, and drainage. Implementing water-efficient technology appears to be crucial for optimizing resource usage and boosting system dependability, encouraging environmental stewardship and economic savings through lower water use and maintenance charges. Related research emphasizes improved sensor technology and climatic variability, which can improve real-time monitoring and adaptive water management tactics for AHUs. Evolving regulatory regulations and building rules highlight the continual need for HVAC systems to be compatible with sustainability goals. The study supports the notion that AHU amount corresponds with wastewater output while also providing insights into environmental factors and operational procedures. These findings argue for integrated methods that combine technical innovation and proactive maintenance to achieve sustainable building operations, highlighting the varied nature of HVAC water management.

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