

Commercial AC System Alternatives for a Case Study Hotel Building in Hot Climate Country: An Inclusive Comparison Analysis



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Abstract Air conditioning (AC) systems are the main energy-significant services in hotel buildings. There is, therefore, remarkable potential to increase energy efficiency use of the hotel AC systems by optimization of both their system selection and operational characteristics. This paper presents an inclusive evaluation of commercial AC systems that can be appropriately functional for a case study star hotel. The hotel considered consists of resorts and villas of cooling load as high as 2400 tons of refrigeration. Site investigation, AC-specified characteristic review, and numerical approach were applied. The evaluation involved operational characteristics, coefficient of performance, and power and energy use per year. The evaluation results showed, for hotel building application, the central AC systems which generally have better diversity factor, could provide flexibility in installed system capacity. The results also showed that the water-cooled chiller system could perform with higher COP compared to the other AC systems. Additionally, the annual energy efficiency of the water-cooled chiller system was also found very superior with energy savings more than 50%. After central water-cooled chiller system, it was found that a modular water-cooled chiller system could also provide an excellent energy performance. Finally, the evaluation results can provide the most suitable AC system alternatives, specifically in hot climate country applications, to hotel facility consultants, hotel building contractors, and hotel owners.

Keywords Inclusive comparison analysis · Commercial AC system · Operational characteristics · A case study hotel building

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1 Introduction

In Indonesia, the building sector, including hotel buildings, uses 50% of energy in general or 70% of total electricity consumption. This makes the sector the largest energy user and even exceeds the industrial and transportation sectors. In terms of energy use, the AC system in buildings consumes 65% of the total energy use in hotel buildings [1]. The hospitality sector itself is growing very rapidly in Indonesia, and tourist visits, especially to Bali, continue to increase.

AC plays a very important role in maintaining thermal comfort in the room, especially for hot and humid climates. The energy consumed by heating, ventilation, and air conditioning in tropical climates can exceed 50% of the total energy consumption of buildings [2, 3], 47% in the US [4] and 30–50% in China [5]. AC systems are the largest energy-significant utility of hotel buildings. Therefore, there is tremendous potential to increase the overall efficiency of the AC system in hotel buildings.

The largest electricity usage in hotel buildings is 70–80% for air- or water-cooled chiller operations, where the chiller is the main sub-system of the AC system. Hotel operational costs can be reduced by optimizing the use of energy in the chiller. Efficient management of multi-chiller systems can be very challenging as an alternative in optimizing their energy use [6]. The overall energy efficiency of an AC system with multi-chillers can have a major impact using the chiller operating sequence arrangement concept [7]. This operational method is a good practice in using multi-chillers with the best efficiency compared to chiller operations which consume more energy [8].

The energy demand for AC system can increase rapidly in the twenty-first century [9]. Higher outdoor temperatures impacting climate change affect cooling energy in terms of higher indoor temperatures and more stringent thermal comfort requirements. In addition, the impact of climate change on AC systems is expected to cause energy demand to soar up to 72%. The biggest consumers of energy related to AC systems come from developing countries. A large increase is expected in South Asia as energy demand for AC systems could increase by about 50% due to climate change [10].

To anticipate these changes, increasing energy efficiency in hotel buildings is currently the main target of energy policy at the regional, national, and international levels. Among building utilities, the increase in energy use of heating, ventilation, and air conditioning systems or better known as HVAC is very significant [11]. Several solutions have been proposed to promote energy conservation such as the development of an AC system equipped with a heat recovery system to heat water [12–16]; maintaining system performance through close monitoring of key chiller parameters including evaporator and condenser approach temperatures [17]; and optimizing the distribution of the cold water circulation system [18]. This could lead to wider adoption of energy efficiency, to support the Government of Indonesia's commitment to reduce greenhouse gas (GHG) emissions by 26% by 2020 [19]. Energy saving is one of the smart solutions to be applied to hotels. Therefore, actions from the building sector to mitigate and adapt to climate change early on from

planning and selecting utilities including energy-significant AC systems become very important to reduce building energy consumption and GHG emissions [20].

This paper presents an alternative evaluation of various AC systems that can be applied to a case study five-star hotel. The hotel is a resort and villa with a peak cooling load based on a comprehensive design result of 2400 TR (tons of refrigeration). The main aspect that becomes the basis of evaluation in this paper is operational characteristics and the energy performance of the AC system including COP, power consumption, and energy consumption per year. Several other aspects were also discussed such as operational flexibility of the AC system, risk of damage, ease of maintenance and repair, and the economic life of the various AC systems evaluated.

2 Material and Methods

The commercial AC systems evaluated in this paper are AC systems that are commonly applied to hotel buildings, especially star hotels. The evaluated AC systems included five types of AC systems, namely: water-cooled chiller, air-cooled chiller, modular air-cooled chiller, water-cooled package (WCP), and variable refrigerant volume (VRV).

The main methods applied in this research include site investigation, AC-specified characteristic review, and numerical approach. Site investigation was conducted to the case study hotel in order to evaluate hotel building characteristics, the AC system used, and cooling demand. Various studies and reviews have also been conducted, among others: a study of the needs and characteristics of cooling loads in various commercial buildings, especially hotel buildings; study of technical specifications covering energy performance, cooling capacity, construction, installation, spatial requirements, and economic life. The study also involved operational characteristics as well as maintenance and repair of various types of commercial AC systems.

The results of the study were then evaluated comprehensively, and comparative analysis was carried out between the cooling load characteristics of the hotel building and the operational characteristics of the air conditioning system. Comparative analysis between various types of AC systems is also carried out to obtain the best AC system priority scale and the one that best suits the needs of hotel buildings, especially from the aspect of energy performance.

3 Results and Discussion

AC System Characteristics. Five commercial AC systems characteristics have been inclusively evaluated. They included water-cooled chiller, air-cooled chiller, modular air-cooled chiller, water-cooled package, and variable refrigerant volume AC systems. The results of the evaluation are systematically detailed below.

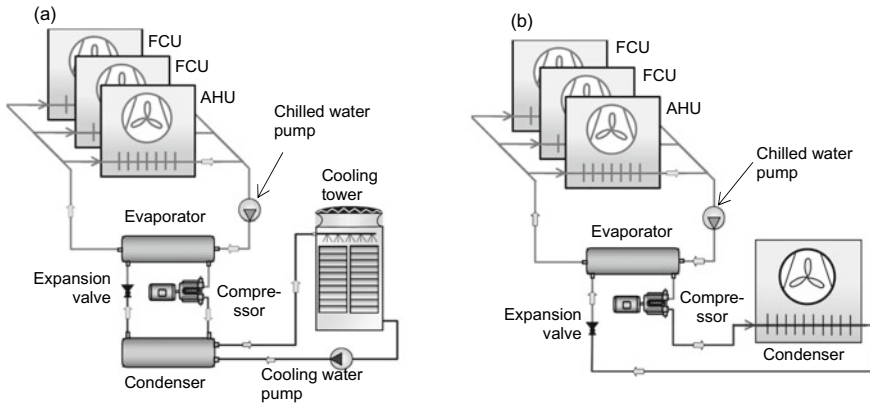


Fig. 1 Schematic diagram of **a** water-cooled chiller and **b** air-cooled chiller

Water-cooled Chiller. The water-cooled chiller is an AC system with a centralized or central system with a condenser cooled by water through a cooling tower system. For application in the case study hotel, the number of chiller units can reach 3 units. Each unit is with a capacity of 600 TR. The AC system produces chilled water with temperature in the range of 6–7 °C. The chilled water is distributed to the loading system in this case: the AHU (air handling unit) or FCU (fan coil unit) using a pump system. On the condenser side, the heat is absorbed by the cooling water and discharged to the environment through a cooling tower system. The schematic of the water-cooled chiller AC system is presented in Fig. 1a.

The characteristics of the water-cooled chiller AC system can be detailed: (i) The cooling capacity can be 20–30% lower than peak load due to diversity factor. For the case study hotel, the diversity factor can reach 70–80%; (ii) the compressor used is a centrifugal compressor with the required number 3 units of 600 TR each; (iii) a minimum enclosed refrigeration plant room is required with a floor area of 168 m² and a minimum height of 4.4 m [21]; (iv) the placement of the cooling tower in the open air is approximately 234 m² [21]; (v) required make up water for cooling tower of 13–15 L/hour per TR cooling capacity [21]; (vi) each room is serviced by an AHU or FCU loading system; (vii) AHU capacity with a range from 5 to 90 TR; (viii) small room serviced by FCU; (ix) the economic life of the water-cooled chiller AC system is generally up to 25 years assuming good maintenance; (x) relatively more flexible for buildings with varying room load conditions, or those equipped with rooms that require large load capacity or high latent loads such as ball rooms or convention halls; (xi) the system can meet the needs of large cooling load with 1 chiller unit; (xii) the refrigeration system is centralized and relatively simple; (xiii) the system has good annual efficiency; (xiv) the possibility of unit disturbance is relatively small because the refrigeration plant room only consists of 3 chiller units (3 × 600 TR).

Air-Cooled Chiller. Air-cooled chiller AC systems have the main difference in their condenser cooling systems compared to water-cooled chiller AC systems. The

condenser of this AC system is cooled directly by the ambient air. The air-cooled chiller is also a centralized AC system. For the case study hotel, the required number of air-cooled chillers can reach 4 units each with a capacity of 450 TR. The AC system can also produce chilled water with temperatures in the range of 6–7 °C. The chilled water is also distributed to the AHU (air handling unit) or FCU (fan coil unit) systems using a chilled water pump system. On the condenser side, the condenser heat is cooled directly by the ambient air. The schematic of the air-cooled chiller AC system is presented in Fig. 1b.

The characteristics of the air-cooled chiller involve: (i) For the case study hotel building applications, the cooling capacity of the air-cooled chiller system can also be 20–30% lower than the peak cooling load due to the diversity factor; (ii) the compressor used is generally a screw type. The hotel requires 4 units of 450 TR each; (iii) a minimum open refrigeration plant room of area 420 m² [21] is required, usually located on the roof top; (iv) each conditioned room is serviced by AHU or FCU; (v) small rooms such as hotel rooms are serviced by FCUs; (vi) the economic life is the same as that of a water-cooled chiller, generally up to 25 years; (vii) relatively more flexible for buildings with various room conditions; (viii) the system can meet the needs of large cooling loads with 1 chiller unit; (ix) the refrigeration system is centralized and relatively simpler than a water-cooled chiller because there is no cooling tower and cooling water system; (x) the possibility of unit disturbance is relatively small because the refrigeration plant room only consists of 4 chillers (4 × 450 TR) completed with piping system, chilled water pump, and the control system.

Modular Air-Cooled Chiller. The installation of the modular air-cooled chiller must be in an open place, usually on the roof top so that the heat dissipation process occurs properly into the ambient air. The distance between the AHU and FCU loading systems and the refrigeration unit can be far because the system is equipped with a chilled water piping system. Chiller operation is very easy and more flexible. In addition, the equipment required is relatively less compared to the water-cooled chiller system. The operation of this modular air-cooled chiller is relatively similar to that of air-cooled chiller in that the capacity is smaller. So, the construction is simpler. The modular air-cooled chiller is an AC system with a non-centralized system, meaning the refrigeration system is spread throughout the building according to loading requirements. The capacity of the modular air-cooled chiller ranges from 14 TR (48 kW) to 66 TR (232 kW) [22]. The AC system also produces chilled water with temperatures in the range of 6–7 °C. The chilled water is also distributed to the AHU (air handling unit) or FCU (fan coil unit) using a pump system. The schematic of the modular air-cooled chiller is presented in Fig. 2a.

The characteristics of the modular air-cooled chiller include: (i) For hotel building applications, the cooling capacity of the modular air-cooled chiller can be 15% lower than the total peak load, because the system can operate semi-centrally with a diversity factor of up to 85%; (ii) the modular installation can be as many as 5 units to get the cooling capacity. Therefore, it is a semi-central AC system (centralized but spread throughout the building) [22]; (iii) for the case study hotel, 8 semi-central systems are required with each consisting of 5 units so that 40 units of modular

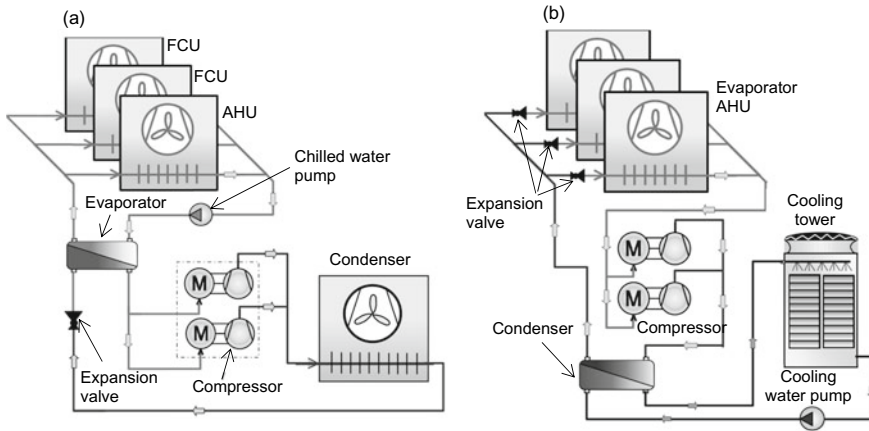


Fig. 2 Schematic diagram of **a** modular air-cooled chiller and **b** water-cooled package (WCP)

air-cooled chiller are required. Each unit is with a cooling capacity of 50 TR; (iv) the compressor used is a scroll inverter compressor; (v) each conditioned room is also serviced by the AHU or FCU system; (vi) the economic life is generally up to 15 years assuming good maintenance; (vii) the system is quite flexible for buildings with various room conditions; (viii) the system is also capable to meet the needs of large loads, and a combined chiller unit is required; (ix) the refrigeration system is semi-centralized or centralized but still spread throughout the building in the form of groups or combined chillers. So, the refrigeration system is relatively more complex; (x) the system has a very good annual efficiency, especially for hotel buildings that have a fluctuating load factor; (xiii) the possibility of unit disturbance is relatively high because the large number of systems required.

Water-Cooled Package. The installation of the water-cooled packaged (WCP) AC system can be on the floor or on the roof top. The distance between indoor and outdoor cannot be far. So, it should be installed close to the conditioned room. The operation of the WCP unit is relatively more complex, because before the refrigeration system is turned on, the cooling tower and cooling water pump must be run first. The schematic diagram of the WCP AC system can be seen in Fig. 2b.

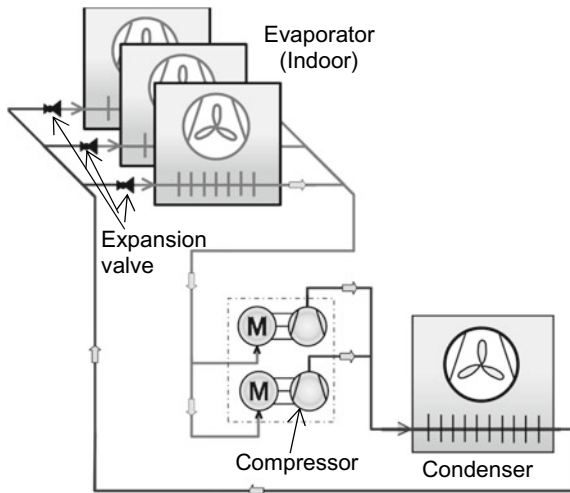
The characteristics and operations of the WCP AC system can be explained as follows: (i) The WCP AC system is direct expansion with water cooling in the condenser; (ii) consists of hanging type WCP with cooling capacity in the range of 9 TR to 56 TR [23]; (iii) for the case study hotel, approximately 48 WCP units with a capacity of 50 TR each are required; (iv) the main components of the refrigeration system, such as the refrigerant piping system, compressor, and condenser, are already one packaged unit; (v) the compressor used is a scroll inverter compressor; (vi) the WCP system condenser is cooled by cooling water from the central cooling tower unit; (vii) required make up water for cooling tower of 13–15 L/hour per TR cooling capacity; (viii) the installed system capacity is the total peak load, because the units work individually for each conditioned room with a diversity factor of 100%; (ix)

installation of the WCP system can be in spread out spaces; (x) each room or group of rooms is served by a WCP system with an AHU system; (xi) the economic life is generally up to 15 years assuming good maintenance; (xii) less flexible, because WCP is a standard unit with a limited number of coil rows; (xiii) the installations are scattered and very numerous and cannot yet be classified as semi-central; (xiv) maintenance costs become more expensive and time-consuming; (xv) less chance of damage than split-type AC system.

Variable Refrigerant Volume. Variable refrigerant volume (VRV) AC system is a type of heating, ventilation, and air conditioning (HVAC) system in a building with a multi-split type that uses refrigerant flow control according to the cooling load requirements. In-building VRV system can save space for installation. Space efficiency is enhanced by compact individual unit sizes, long maximum piping lengths. In addition, the system provides superior design flexibility especially in that layout changes can be made easily. The outdoor unit can be placed on the floor or on the roof top. The schematic diagram of the VRV AC system is presented in Fig. 3.

The characteristics of the VRV AC system can be described as follows: (i) VRV AC system is an AC system with direct expansion and not central. The installation is spread throughout the building according to the cooling load of the conditioned room; (ii) consists of indoor unit and outdoor unit, where the installation of outdoor unit must be provided on each floor; (iii) capacity range from 6 to 30 TR; (iv) for the case study hotel, approximately 80 VRV units with a capacity of 30 TR each are needed [24]; (v) cooling of the condenser with ambient air; (vi) the amount of refrigerant flow in the system is variable according to the cooling load; (vii) the installed capacity is the total peak load, because the units operate individually with a diversity factor of 100%; (viii) the number of outdoor units can be very large, and their installation can be a problem for esthetically pleasing hotel buildings; (ix) each conditioned room is served by an indoor unit (IU) with a capacity range from

Fig. 3 Schematic diagram of a variable refrigerant volume AC system



0.5 TR to 20 TR; (x) the economic life is generally up to 15 years assuming good maintenance; (xi) less flexible, because the indoor unit is a standard unit with a limited number of row coils; (xii) for large spaces, many units are needed scattered around the room; (xiii) maintenance costs are more expensive and time-consuming compared to chiller systems; (xiv) there may be more refrigerant leaks, because pipe installation, refrigerant charging, and tests carried out at the installation site.

Performance and Energy Consumption Analyses. The results of the study of the performance of the investigated commercial AC system show various variations in performance. Their performances are influenced by heat rejection system in the condenser and the optimization of heat transfer in the heat exchanger components such as evaporator. Performance is also greatly influenced by the type of compressor and refrigerant used. The performance of the AC system also directly affects its energy consumption. Table 1 presents a comparison of performance and power consumption as well as annual energy consumption which was numerically determined based on the assumption of a use factor of 75% which means that the AC system is only used for 75% of the total hours in one year.

Based on the characteristics of the AC system and the results of the analysis presented in Table 1, the advantages and disadvantages of each AC system can be identified when applied to the case study hotel building with a large cooling load. The hotel building has characteristics with very fluctuating load factors and provides advantages for central AC systems with relatively better diversity factors. So that the installed system capacity can be smaller than the peak cooling load of the building.

Table 1 Result of investigation on the performance and energy consumption of the AC systems

AC system	Installed capacity (TR)	COP	Efficiency (kW/TR)	Power (kW)	Annual energy use (kWh)
Water-cooled chiller (centrifugal compressor) [25]	1800	5.79–6.29	0.61–0.56	1053	6,918,210
Air-cooled chiller (rotary screw compressor) [26]	1800	3.34–3.40	1.05–1.03	1872	12,299,040
Modular air-cooled chiller (inverter scroll compressor) [22]	2000	4.10–4.35	0.86–0.81	1670	10,971,900
Water-cooled packaged (WCP) (inverter scroll compressor) [23]	2400	3.55–4.29	0.99–0.82	2172	14,270,040
Variable refrigerant volume (VRV) (inverter scroll compressor) [24]	2400	3.43–3.75	1.03–0.94	2364	15,531,480

Assumption AC system operated at use factor of 75% (only 6570 h in a year). The variation of installed capacity due to diversity factor of AC system used

From the energy performance aspect, it can also be identified that the water-cooled chiller type AC system has the highest COP compared to other AC systems. Combined with the advantage that the installed capacity is also small, the annual energy consumption for water-cooled chiller is also very superior with energy savings of more than 50% compared to WCP and VRV type AC systems. Modular water-cooled chiller also has superior energy performance after water-cooled chiller. This AC system consumes 10.97 GWh of energy per year. With that amount of energy consumption, the modular air-cooled chiller has superior energy performance compared to the air-cooled chiller, WCP, and VRV AC systems.

The results of this study can provide alternative options for hotel owners, consultants, and building contractors in determining the most suitable AC system to be applied. It is also very useful for researchers to conduct further studies on various applications including the economic feasibility aspect of various AC systems for various commercial building applications.

4 Conclusions

Evaluation of various types of AC systems for a case study hotel building applications with large cooling capacity has been carried out. Based on the characteristics of the AC systems and the results of the analysis, it was found that the water-cooled chiller AC system could perform with the highest COP compared to other AC systems. Combined with the advantage that the installed capacity is also small, the annual energy consumption of the water-cooled chiller was also very superior with energy savings of more than 50% compared to the WCP and VRV type AC systems, and around 44% compared to the air-cooled chiller, and 37% compared to modular air-cooled chiller.

Modular air-cooled chiller also has superior energy performance after water-cooled chiller. The AC system consumes 10.97 GWh of energy per year. With that amount of energy consumption, the modular air-cooled chiller also has exceptional energy performance compared to the air-cooled chiller, WCP, and VRV AC systems.

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