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Air Conditioning System Performance of a City Hotel Appraised for Energy Use Efficiency

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ABSTRACT

This paper presents results of a study on the performance of split air conditioning (AC) and overall energy consumption of a city hotel in Bali, Indonesia. The study applied a practical global approach to appraising energy performance of the AC system, overall electrical energy consumption of the hotel and frequent compressor damage as the impact of installation methods of the existing AC systems. The results obtained indicate that improper AC system installation method can reduce their energy performance which include COP (coefficient of performance), EER (energy efficiency ratio), and SEI (system efficiency index). The finding also shows improper installation method can cause enormous compressor damage. Within three years, as many as 54 compressors from 90 existing AC system in a particular building were damaged. Overall number of compressors that have been faulty in that period can reach 76 units accounted for about 23.1% of the total AC systems installed in the hotel. It is also found there is a reduction on AC system cooling capacity.

1. Introduction

Hotel is a unique commercial building equipped with various facilities. One of the hotel facilities is air conditioning (AC) for the convenience of visitors. AC system has become the largest end user of energy in the building sector. Improving building designs and optimization on the AC systems in order to reduce cooling load and energy use is the subject of many researches in tropical climates. More effort is required for developing countries to achieve low building cooling load and energy use, hence building energy appraisals are becoming increasingly sophisticated.

Interestingly, urbanization, population growth, the increase of demand for comfort levels and favorable thermal environment in buildings together with the increase in time spent indoors seem to ensure that the trend of increasing energy demand in building sector will continue to increase in the future [1]. Hotel is one of the commercial buildings that is unique among other buildings. The hotel building has many areas with different facilities and diverse variability in the room that guests expect. This leads to a different energy consumption compared to other buildings [2]. Buildings

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account for the majority of energy consumption worldwide [3-5]. For industrialized countries, energy consumption of buildings could range from 42 up to 45% [6-8].

Concerning the main parameter of building thermal performances used to measure AC systems, specifically for city area, is related to the site-specific temperature. Therefore, accurate study of local conditions is essential. The accuracy of building thermal performance simulations can be frequently improved by paying attention to a phenomenon which is known as Urban Heat Island (UHI). This phenomenon has a consequence of an increase in air temperature [9,10]. UHI affects energy consumption of the buildings, which in turn affects the city environment [11]. Extensive literatures discuss the UHI phenomenon can be found in the study by Zhou *et al.,* [12] and Santamouris *et al.,* [13] and its effects on building energy consumption have been reported in the study by Li *et al.,* [14], Palme *et al.,* [15], and Lima *et al.,* [16].

Energy-efficient retrofitting interventions and policies to reduce electricity consumption and costs have been explored in many countries [17-21]. The interventions and policies include energy efficiency for building envelopes and windows [22-25]. Energy consumption mainly comes from the use of Heating, Ventilation and Air Conditioning (HVAC) systems [26,27]. Poor thermal performance and low efficiency of HVAC systems of most buildings result in high energy consumption [28-29].

One method of reducing building energy consumption is through optimizing equipment operation and control, like modification of set-point temperature which can be adapted to external climatic conditions but maintains an acceptable level of comfort [30,31]. Using adaptive set-point temperature can optimally reduce energy consumption in the building sector, mainly because of its effect on HVAC system performance [32-34]. Modification of set-point temperature to higher level actually provide the HVAC system to operate at higher evaporation temperature by which can contribute to better energy performance [35,36]. Additionally, the use of a set-point temperature appropriate to the environmental characteristics of each area can reduce energy consumption of the building without implying a large economic investment [37].

AC system plays a very important role in maintaining indoor thermal comfort of the hotel, especially for tropical and humid climates. In tropical climates, the energy consumed by HVAC system can exceed 50% of the total energy consumption of a building [38]. Hence, there is tremendous potential to improve the overall efficiency of AC system in buildings. One method of improving AC system efficiency is through application of heat recovery to be integrated with the AC system [39] and optimization of the heat recovery system by utilizing thermal energy storage [40]. Large amount of energy use in hotel buildings contributes to high operational costs by 17-30% and significant contribution to greenhouse gas emissions, global warming and climate change [41-43].

Initiatives for Nearly Zero Energy Buildings are increasingly important for tackling climate change and reducing energy use [44,45]. Greater effort is required from the developer to achieve these objectives, and energy appraisal is becoming increasingly sophisticated [46]. This study also involves energy appraisal of a city hotel in Bali, Indonesia. The appraisal was conducted to building envelope, AC system description including user practices, annual electricity consumption associated with cooling zones. The appraisal also provides possibility to determine potential improvements in reducing energy consumption [47,48]. By discovering energy saving potentials, it can help use energy more efficiently in city hotel buildings and reduce CO_2 emissions to the environment for sustainable development.

The city hotel investigated in this study uses split type AC system. There are many factors found to affect the AC performance which include set-point temperature, high temperature condensation, low evaporation temperature, extremely hot compressor, noisy compressor, compressor stuck, and very low degree of superheat refrigerant entering the compressor. The main problem appeared which related to the function of AC system was that many compressors had started to be damaged since about two up to three years after the year of hotel opening. Though service life of split type AC system in normal operating conditions is up to 15 years and service experts recommend users to consider replacing split type AC system after every 10 years [49]. Problem related to energy performance was also existed which could be determined from instant power measurement and assessed from energy consumption of the hotel that was found to be far from the criteria of an energy-efficient city hotel.

This paper presents performance evaluation on energy performance of split type AC applied for a city hotel in Bali, Indonesia. Assessment on the AC performance including problems associated with system functionality and energy performance due to AC system installation are also elaborated and discussed. A very important finding about the impact of poor installation of the AC systems on compressor life was also presented and discussed. This paper, additionally, proposes energy efficiency improvement strategy and economic practices based on energy appraisal results and its impact to electrical energy costs. It is also deeply discussed that by reducing level of energy consumption of a city hotel, it can certainly provide a financial impact.

2. Materials and Methods

2.1 City Hotel Building Characteristic

The investigated city hotel is located in Denpasar city of Bali province, Indonesia. The hotel comprises 4 buildings including 1 hotel building (Building-1) and 3 residence buildings (Buildings-2, 3, and 4). The hotel building contains 90 guestrooms and convention center which a place for meetings, incentive, convention, and exhibition consisting of 3 convention halls and 7 meeting rooms. Whereas the residence buildings comprise 96 guestrooms which make the hotel have total guestrooms of 186. As a city hotel, the entire floor area of the buildings is around 7842 m^2. The hotel has been operating since 2014.

2.2 Hotel Building Envelope

Facades of the Building-1 with 90 guestrooms and convention center face north and south. The facades are considered to have a good design because they are facing to directions with relatively low solar heat gain potential. Around the facades, the hotel environment is facilitated by a green landscape with a variety of shady plants. The concept, which is also called a green landscape, can provide a cooling effect on fresh air or infiltration air and in the end give a fairly low heat gain effect on the guestroom load. Green landscape also provides cooling effect on the residence buildings. The north, south facade and shading of the buildings can be seen in Figure 1.

Fig. 1. The north and south facades as well as internal shading of the hotel buildings

Figure 1 also shows façade-wall of the hotel buildings which uses glass-window with window and wall ratio of less than 25%. The use of glass windows allows sunlight to penetrate inside the guestrooms and can take advantage of daylight for the guest room lighting. Regarding the potential heat gain through the glass, internal shading can reduce this consequence. In general, designers of the hotel have succeeded in implementing environmentally friendly design to minimize heat gain through the building envelope by placing the façades north and south and applying green landscape. Internal shading can also minimize infiltration air and penetration of solar radiation into the guestrooms.

2.3 Installed Air Conditioning System
2.3.1 Air conditioning system and installation

The hotel uses unitary type AC systems which can be grouped according to the building being served. Building-1 uses concealed split type AC. The condensing units (outdoor) of the AC systems for floors 3rd, 4th and 5th are installed on the roof of the building and for floors 1^{st} and 2^{nd} are installed outside the building adjacent to the respective floors. Meanwhile, the indoor unit is a concealed type placed above ceiling in front of bathroom. Each indoor unit is equipped with a blower, supply grill, ducting from evaporator coil to supply grill and an air filter. The filter is used to clean air from the room before it re-circulates to the evaporator coil. The AC system installed in each guestroom is specified for cooling capacity of 9000 (Btu h-1). Installation of the outdoor units and the grill of indoor unit can be seen in Figure 2. All AC systems in the hotel are still using refrigerant R-22.


Split type AC: Outdoor Unit   Front grill of the Indoor Unit
Fig. 2. Split AC system applied for Building-1

In the Building-1, the indoor unit used is a concealed type with forced flow. This indoor type chosen is quite uncommon. As a comparison, indoor of wall mounted type generally with induced flow. The concealed type with forced flow has a disadvantage of having air back pressure due to air burst into the evaporator coil. Back pressure causes the blower to require a higher static pressure head than induced flow. If the blower specifications used are the same as the induced flow, it may result in air flow shortage and it can be difficult to meet minimum flow requirements of the optimum cooling effect. It can get worse if the evaporator coil is dirty. Another drawback of a forced flow concealed type indoor construction which mounted above ceiling is that the difficulty of access to evaporator coil for regular cleaning. The evaporator is blocked by ducting from the indoor to the supply grill. Cleaning the evaporator coil is time consuming especially in preparing the access. For cleaning the evaporator only, the guestroom cannot be sold for about three days. This is one reason why cleaning the evaporator cannot be scheduled regularly by hotel management.

Buildings-2, 3 and 4 use wall mounted split type AC systems. Most of the indoor units are installed at a higher position than the outdoor units. Only the AC systems for the 5th floor of each building are installed on the roof top with the outdoor position higher than the indoor unit. Typical installation of the AC systems can be seen in Figure 3.

Split type AC: Outdoor unit   Indoor unit-wall mounted

Fig. 3. Split AC system installed in residence buildings

The AC system capacities for residence buildings according to manufacturer specifications vary from 6750, 9000, 13500 and 18000 (Btu h^{-1}). AC system with 6750 (Btu h^{-1}) cooling capacity installed in Building-2, 3 and 4 are respectively as many as 70, 68 and 75 units. While the convention center uses split type AC systems. The outdoor units of the AC systems are shown in Figure 4. The AC systems used consist of split duct and split cassette types.

Fig. 4. The outdoor units of split AC systems for convention center

2.3.2 Ventilation system

The ventilation system is designed to maintain air quality so that it is comfortable and healthy. The system controls intake of clean, pollutant-free and odorless fresh air into the guestrooms, convention halls, meeting rooms, and offices with a certain amount according to the function of the room. It maintains the O_2 (oxygen) content at a sufficient level for guests or residents and prevent level of CO_2 (carbon dioxide) concentration above 1000 ppm (parts per million).

The ventilation system has not been integrated with the current AC system. Partial ventilation can occur due to the presence of an exhaust fan in the toilet which can create negative pressure in the toilet and also in the guestroom. This causes air in the corridor to enter the guestroom through the door opening or when the door is opened. There is also a possibility that outside air can enter from the window, although it is very small because the type of window is air tight (see Figure 1). The window, however, is equipped with an open and close mechanism, so that guests can provisionally open the window, especially when they require better ventilation. Relying on air from the corridor is actually an inaccurate concept, because corridors are usually designed with negative pressure, with the intention that corridor air does not enter the guestrooms. For convention center, fresh air is only obtained from infiltration through the doors. According to ANSI/ASHRAE Standard 62.1 [50], for hotels: whether guest rooms, meeting rooms, convention halls or offices in order to obtain good air quality, a minimum ventilation rate (minimum fresh air flow rate) of 2.5 LPS (liter per second) per person is required. This is about 5 CFM (cubic feet per minute) per person.

Ventilation can result in additional cooling load from the AC systems and can also further increase the operating costs. But in this modern era, operating costs can be reduced by reducing energy consumption through the installation of an efficient AC systems and adequate maintenance. On the other hand, the cost and quality of maintenance can also be affected by easy access to the AC systems, so the selection of the AC system installation and the provision of access for maintenance are also very important factors to consider.

2.4 Piping Installation and System Construction

The installation and construction methods of the split AC system in Building-1 can be divided into 2 groups, namely: (i) Group I: floors 1st and 2nd; (ii) Group II: floors 3rd, 4th and 5th. The AC systems in Group I are the AC systems that have been reinstalled from an arrangement where the outdoor units placed on the roof top of the building with elevation more than 15 m above the indoor unit to the opposite arrangement where the outdoor units are installed with elevation below the indoor units. This change was done after the hotel in operation for approximately 2 up to 3 years (2017). While Group II comprises split AC systems with arrangement where the outdoor units installed on the roof top of the Building-1 with elevation of about more than 10 m above the indoor units. Other buildings were applied installation method as used in Group I of the Building-1.

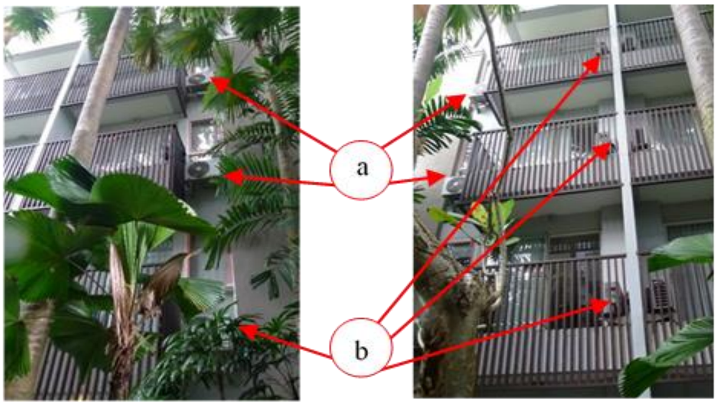
Installation of outdoor units on the roof top of Building-1 and the piping system can be seen in Figure 5. It can be clearly observed that the installation of the outdoor unit does not consider access to maintenance and repair, nor space for ambient air circulation which could obstruct heat dissipation from condensers.

Condensing unit installation   AC system piping installation

Fig. 5. Condensing unit and piping installations of the hotel building

Installation of the refrigerant pipe for AC systems in Building-1 seems to have problems with the length of the pipe which is far exceeding the length recommended by the manufacturer of 10 m maximum for AC system of 9000 (Btu h^{-1}) or lower cooling capacity. In addition, the installation elevation between indoor and outdoor units by the manufacturer is usually limited to a maximum elevation range from 5 m up to 7 m. The elevation difference, especially for cases where the outdoor units are installed above the elevation of the indoor units, becomes very critical. Some issues on the pipe insulation such as damaged insulation, discontinued insulation, pipe without insulation were also found in the installation of AC system for Building-1.

Pipe installation of the AC systems in Building-2, 3, and 4 (the Residence buildings) is relatively better than that in Building-1. The installation of the outdoor units can be seen in Figure 6. In general, the concept of outdoor installation from the side of cooling air circulation is very good, that is, it is open and there are no walls or objects that block the flow of condenser air. In addition, almost all air conditioners are installed by placing the indoor units at a higher elevation than the outdoor units, except for the AC system for the 5th floor, the outdoor units are placed on the roof top of the buildings. There are several aspects that need to be addressed by hotel management with regard to AC systems in Building 2, 3 and 4, namely access to the outdoor units of the AC systems for maintenance and repair. Some outdoor units are installed on walls that are difficult to access for maintenance and repair. Other outdoor units have been installed with a proper approach to reach the units for inspection and maintenance as shown in Figure 6.



a. installation with very difficult access for maintenance;
b. installation with good access for maintenance

Fig. 6. Outdoor unit installation of the AC system in residence buildings

Installation of the AC system at the convention center seem to be considering access for maintenance and repair. Additionally, the installation has placed the outdoor unit elevation below the indoor unit. The outdoor unit installation of the AC systems is illustrated in Figure 4.

2.5 Methodology and Assumptions

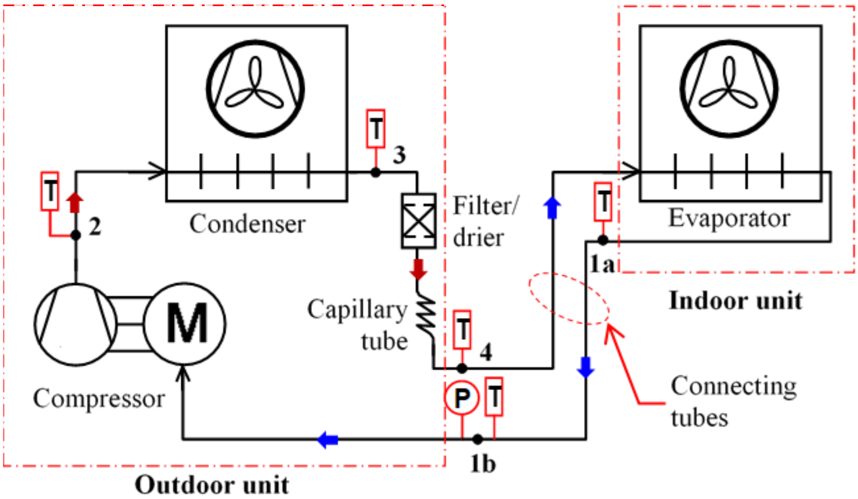
Energy appraisal is one step in a comprehensive energy saving management and program related to the AC (Air Conditioning) systems in hotel buildings. Without energy evaluation, it could be difficult to measure system efficiency, performance and potential energy savings through system optimization, modification and development. Evaluation of the impact of AC system installation methods on energy performance of the AC system, overall electrical energy consumption of the hotel and frequent compressor damage used primary data obtained from direct measurement and secondary data gathered from hotel management together with data from site observation.

Internal method was applied for direct measurement in this appraisal. By using this method, it provides possibility to thermodynamically develop refrigerating process and cycle of the AC system. It can also offer a better assessment about system efficiency which based only on a short period and instant measurement on site [51]. Parameters, that are necessary to be measured using this method, include surface temperatures of the refrigeration system, refrigerant pressures and electric power. Data and information required in this appraisal were gathered in two groups. Firstly, secondary data was obtained from hotel management, hotel engineers as well as from manufacturer. Secondly, primary data was directly measured on the AC systems in field. Direct observation on the AC system and other supporting facilities which include installation, operation, maintenance and repair has also been performed to accomplish a comprehensive information and data required for the analyses. For investigation purposes, a data logger system for measuring temperature and power consumption on the AC system were installed and set up. To assist the investigation process, appraisal instruments including digital and infra-red thermometers, digital air-flow meters, power analyzers, hot wire temperature measuring instruments, thermocouples, and a digital camera were also used.

a. Power and temperature loggers b. Handheld manual instruments

Fig. 7. Handheld instruments for automatic and manual measurements

The purpose of making direct measurements and observations is to obtain accurate data based on actual operating conditions. Measurements were made using manual and automatic methods. Operational data was recorded directly, automatically and continuously at the same time for various parameters using a data logger (Figure 7(a)). Whereas the working pressure of the system, air flow rate, surface temperature and relative humidity (RH) of the air were measured using manual measurements (Figure 7(b)). Data obtained were recorded manually using handheld instruments.



1a = evaporator outlet; 1b = compressor suction line; 2 = compressor discharge line; 3 = condenser outlet; evaporator inlet; T = temperature measurement; P = pressure measurement

Fig. 8. Schematic diagram of a split type AC system completed with site measurement points for energy performance investigation

Data obtained from measurements and observations were processed using spreadsheet and EES (Engineering Equation Solver) programs. By using these programs, thermal properties of refrigerant at various operating conditions can be retrieved and energy performance of the AC system can be investigated and simulated. The programs were also used to estimate AC system performance under different operational conditions.

Performance of the AC system was determined by using thermodynamic analysis on the refrigeration cycle. Performance parameters used in the analysis were measured in every 30 seconds for about 3 hours. Positions of the measurements are illustrated in a schematic diagram of the AC system as shown in Figure 8. Measurements were randomly performed using 5 samples of AC systems (two for Building-1 and one each for Building-2, 3 and 4).

Applying internal method, evaluation on the performance of the AC system which involves cooling capacity (Q_{cool}) and electric power consumption of the compressor ($W_{e,com}$) can be done through temperature and pressure measurements in the refrigerant circuit. Temperatures and pressures of refrigerant at various part of the AC system can be used to determine specific enthalpy change of the refrigeration process in the system cycle. Cooling power or well-known as compressor work rate ($W_{w,com}$) was estimated from heat loss to surrounding and electric power of the compressor. For an AC system using hermetic compressor, the heat loss factor may be ranging from 3% up to 10% calculated from electric motor power and specifically for compressors operated at normal ambient conditions, a fix value of 7% can be applied [51].

Assumptions were also taken to simplify the system evaluation which include: isenthalpic expansion in the capillary tube, insignificant pressure drops in the heat exchangers and connecting tubes, and 7% heat loss factor in the compressor. Refrigerant exiting the condenser is assumed to be saturated liquid due to difficulty to installed pressure measurement on the high pressure side of the existing system. There is no service valve at condenser side. To install a pressure measurement would require modification of the tubing system and make the AC system unable to operate for hotel services. This should be avoided in this appraisal. Based on these assumptions, refrigeration cycle of the AC system used for analysis is illustrated in a pressure-enthalpy diagram as can be seen Figure 9.

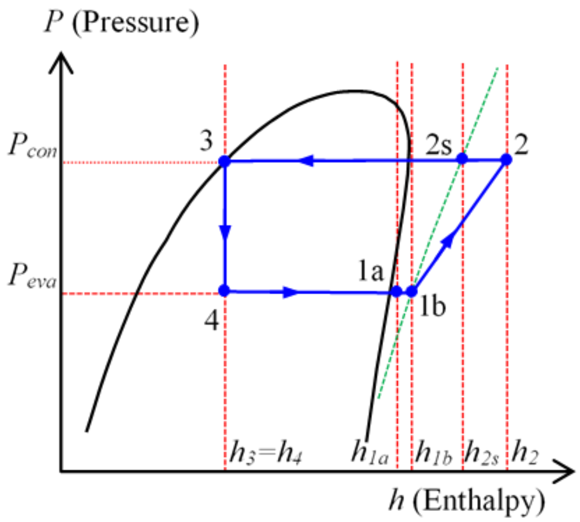


Fig. 9. Refrigeration cycle of the AC system in pressure-enthalpy diagram used for analyses

Taking into consideration heat loss factor (f_q), then compressor work rate ($W_{w,com}$ in kW) can be determined from Eq. (1).

$$W_{w,com} = (1 - f_q)\, W_{e,com} \qquad \text{(kW)} \tag{1}$$

where $W_{e,com}$ is electric power consumption of the compressor in kW. How far the compressor deviates from an isentropic compression can be determined from isentropic efficiency which can be calculated from Eq. (2).

$$\eta_s = \frac{(h_{2s} - h_{1b})}{(h_2 - h_{1b})}\, 100\,\% \qquad (\%) \tag{2}$$

where η_s = isentropic efficiency of the compressor (%); h = specific enthalpy of the refrigerant at measuring points (kJ kg^{-1}), corresponding subscripts refer to Figure 8 and Figure 9.

In this appraisal, one key parameter used as performance indicator of the AC system is COP_m (Coefficient of Performance; subscript m stands for measured) which expresses ratio of useful heat or cooling capacity (Q_{cool} in kW) over electric power consumption of the compressor ($W_{e,com}$ in kW) as formulated in Eq. (3).

$$COP_m = \frac{Q_{cool}}{W_{e,com}} \tag{3}$$

where Q_{cool} can be determined from:

$$Q_{cool} = \dot{m}_{ref}\,(h_{1a} - h_4) \qquad \text{(kW)} \tag{4}$$

$$\dot{m}_{ref} = \frac{W_{w,com}}{h_2 - h_{1b}} = \frac{(1 - f_q)\, W_{e,com}}{h_2 - h_{1b}} \qquad (\text{kg s}^{-1}) \tag{5}$$

where $\dot{m}_{ref}$ is refrigerant mass flowrate (kg s^{-1}). Solving the Eq. (3)-(5), the COP_m of the AC system then can be also calculated by applying specific enthalpy changes of the compression process (in compressor), heat absorption process in the evaporator together with compressor heat loss as shown in Eq. (6). Subscripts in the equations refer to Figure 8 and Figure 9.

$$COP_m = \frac{(1 - f_q)(h_{1a} - h_4)}{(h_2 - h_{1b})} \tag{6}$$

Others key performance indicators used of the AC system are *EER* (Energy Efficiency Ratio) and *SEI* (System Energy Index). *EER* is a measure of efficiency correlated to COP_m but its unit should be in Btu h^{-1} W^{-1}. Then, the *EER* of the AC system can be calculated from Eq. (7).

$$EER = 3.412\, COP_m$$

$$EER = 3.412\, \frac{Q_{cool}}{W_{e,com}} \qquad (\text{Btu h}^{-1}\ \text{W}^{-1}) \tag{7}$$

SEI is also a measure of efficiency but it provides advantages compared to COP_m. By using *SEI*, system efficiency can be obtained at restricted field measurements. SEI is defined as the ratio of calculated COP_m over coefficient of performance of ideal process or the maximum theoretical *COP* at desired operating conditions, which is also known as Carnot COP (COP_C). *SEI* can be applied for optimization of energy system and as a guide for selecting the main parts of an AC system. *SEI* and COP_C can be calculated from Eq. (8) and Eq. (9) respectively.

$$SEI = \frac{COP_m}{COP_C} = \frac{(1-f_q)(h_{1a}-h_4)}{h_2-h_{1b}} \frac{(T_{con}-T_{eva})}{T_{eva}} \tag{8}$$

$$COP_C = \frac{T_{eva}}{(T_{con}-T_{eva})} \tag{9}$$

where f_q = compressor heat loss factor; h = specific enthalpy of the refrigerant at measuring points (kJ kg^{-1}), relevant subscripts refer to Figure 8 and Figure 9; T_{eva} and T_{con} are evaporation and condensation temperatures respectively (in Kelvin).

Energy performance of the AC system is directly related to the cooling load characteristics and cooling capacity of the AC system and heat dissipation in the condenser unit. The mismatch between building cooling demand, AC system cooling capacity and heat dissipation in the condenser can affect the performance of the AC system. In order to comprehensively investigate the performance of the AC system, the cooling demand of the hotel rooms was also estimated using the EES program. The cooling demand estimation method is usually applied by combining the diversity factor based on the cooling demand data analysis and how often each cooling demand element occurs. The diversity factor also shows that all cooling demands do not occur at the same time and also not always at their maximum value. For hotel buildings using unitary AC system, however, the diversity factor can be assumed as a room peak load which is considered 100% of the calculated load [52].

The appraisal also involves energy consumption profile of the hotel which presented for two or four years. Energy performance of the hotel has been identified by using Energy Use Intensity (*EUI*) and Guest Energy Intensity (*GEI*). *EUI* is calculated from the ratio of energy consumption (kWh) over floor area (m^2) to be conditioned within a certain period of time (per month and per year). Whereas GEI is a parameter that shows energy consumption (kWh) per number of guests staying (guest night) and it is evaluated monthly.

3. Results and Discussion

3.1 AC System Energy Performance

Operational quantities required for AC system evaluation have been measured and recorded. Five samples of AC systems were considered. The results of the measurement are given in Table 1. Data presented are average values of every 30 seconds for 3 hours' record. It can be seen the AC systems of Group II (AC-1b) have worked with highest: compressor discharged temperature (T_2), condensation temperature (T_{con}), evaporator degree of superheat and the lowest evaporation temperature (T_{eva}). The main cause this issue can occur is that the outdoor unit of the AC systems are installed very closed to each other which can obstruct fresh air flow that cools the condenser. Dirty evaporator can also cause the problems due to the indoor units are installed without proper access for regular cleaning or maintenance. From the measurement data, it can also be identified there is significant temperature gain for about 4 °C along the connecting pipe of indoor and outdoor units. It can increase further degree of superheat of the refrigerant entering the compressor which can also lift discharge temperature (T_2). Damaged insulation and pipe length much longer than specified by manufacturer is very likely to be the cause. Other AC systems (AC-1a, AC-2, AC-3 and AC-4) are found to have normal operational parameters.

Data obtained was processed using EES program. Energy performance of the AC systems were thermodynamically determined and the results are shown in Table 2. Power consumption of the AC systems was closed to their specifications. Their cooling capacity, however, varied from 8120 up to 9068 (Btu h^{-1}). AC-1b was found to have the lowest cooling capacity. It was again due to dirty evaporator because the indoor unit was installed without proper access for regular cleaning. Dirty evaporator could cause weak air flow through the evaporator coil with an average air velocity coming out of the inlet grill of 1.16 (m s^{-1}) at high speed fan position. The air flow rate was found 0.125 (m^3 s^{-1}) or 264 (ft^3 min^{-1}). Normal airflow at maximum speed is specified for about 375 (ft^3 min^{-1}). This resulted in the AC systems in Group II of Building-1 could not perform as good as other AC systems with COP_m 3.31 which accounted for about 6% lower than their specifications. Other AC systems were found to perform as specified by their manufacturer with COP_m range between 3.49 and 5.53.

Table 2 also contains AC systems compressor efficiency which was calculated from specific enthalpy of ideal and actual compression processes based on system pressure and temperature values using the internal method. *EER* and *SEI* of the AC systems are also presented. *EER* is correlated to COP_m and calculated from Eq. (7). While *SEI* has been determined from the ratio between COP_m and Carnot *COP* based on reference temperatures of condensation and evaporation at condenser and evaporator side respectively.

Table 1
Measurement results of the operational quantities required for determining the AC system energy performance

Measured quantities	Units	AC-1a	AC-1b	AC-2	AC-3	AC-4
Ambient temperature	°C	30	31	30	30	30
Evaporation pressure (P_{eva}),	Psi	70	69	70	71	72
with corresponding evaporation temperature (T_{eva})	°C	5.0	4.6	5.0	5.4	5.7
Compressor inlet refrigerant temperature (T_{1b})	°C	11.7	13.8	10.2	12.7	12.9
Compressor outlet refrigerant temperature (T_2)	°C	84	88.7	83.0	86.2	87.2
Temperature of refrigerant out evaporator (T_{1a})	°C	11.5	9.8	10.2	12.7	12.9
Temperature of refrigerant out condenser (T_3=T_{con})	°C	47.1	48.6	47.2	48.1	48.4
Degree of superheat refrigerant at inlet compressor	K	6.7	8.8	5.2	7.7	7.2
Guestroom air temperature	°C	26	25	26	25	25
Guestroom air RH	%	66	64	65	63	64

AC-1a = an AC system of Group I in Building-1; AC-1b = an AC system of Group II in Building-1; AC-2, 3 and 4 = AC systems in Building-2, 3 and 4 respectively

Compressor efficiency of all AC systems are in a good range from 72.5% to 75.6%. Isentropic efficiency of AC system's compressor commonly ranges between 65% and 90%. With regard to *EER* and *SEI* of the AC systems, it is found that the AC-1b, similar to its COP_m, has the lowest *EER* of 11.28 (Btu h^{-1} W^{-1}) and *SEI* of 51.9% which are accounted for 6.0% and 6.9% respectively lower than the specifications. However, all evaluated AC systems are included in excellent *SEI* grade with *SEI* value more than 40% as proposed by Lane *et al.,* [51], which means the AC-1b also has excellent *SEI*. This also confirms that in term of energy consumption, AC-1b is not the AC systems that has the highest power consumption as shown in Table 2.

From these results, it can be summarized that the AC systems of the hotel buildings, in general, still consume energy in the normal range. Even though energy performance parameters of some AC systems such as cooling capacity, COP_m, *EER*, and *SEI* are found to be lower than the specifications. However, the hotel management still faces some complaints especially for Building-1 that some guestrooms are not cool enough. The analysis results have proven that the complaints are mainly caused by some AC systems are not being able to provide sufficient cooling due to their low cooling capacity. Even though their power consumptions remain in the normal range.

Table 2
Energy performance parameters of the AC systems simulated in EES program based on data obtained from the field

Simulated parameters	Units	AC-1a	AC-1b	AC-2	AC-3	AC-4
Specified cooling capacity (name plate)	Btu h^{-1}	9000	9000	9000	9000	9000
Specified power consumption (name plate)	kW	0.75	0.75	0.75	0.75	0.75
COP based on specified data	-	3.52	3.52	3.52	3.52	3.52
Isentropic efficiency of the compressor (η_s)	%	73.0	73.0	72.5	75.6	74.1
Compressor power ($W_{e,com}$)	kW	0.70	0.72	0.71	0.75	0.72
Compressor work rate ($W_{w,com}$)	kW	0.65	0.67	0.66	0.70	0.67
Calculated cooling capacity (Q_{cool})	kW	2.47	2.40	2.48	2.66	2.54
	Btu h^{-1}	8429	8120	8448	9068	8656
COP_m	-	3.53	3.31	3.49	3.54	3.52
COP_C	-	6.60	6.37	6.57	6.45	6.53
EER (Energy efficiency ratio)	Btu h^{-1} W^{-1}	12.04	11.28	11.90	12.09	12.02
SEI (System energy index)	%	53.5	51.9	53.1	55.0	53.9

3.2 Hotel Energy Profile

Appraisal on the hotel energy usage has shown that almost all energy needs for hotel service facilities come from electrical energy. Monthly electrical energy consumption of the hotel is around 186 MWh and 168 MWh which is equivalent to electricity consumption of 2231 MWh and 2020 MWh per year respectively for year 2018 and 2019. Monthly variation in electricity consumption of the hotel for 2018 and 2019 can be seen in Figure 10.

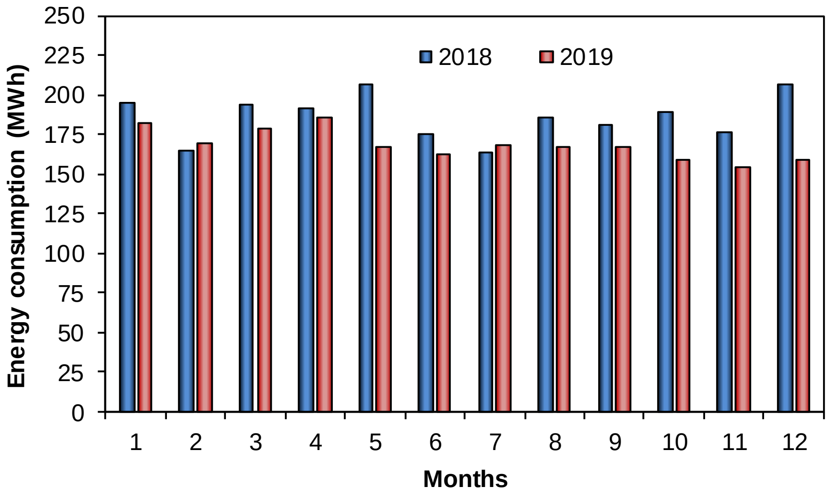


Fig. 10. Variation of monthly energy use of the hotel 2018 and 2019

The electricity consumption correlates with hotel occupancy rates as one of the parameters that can affect electricity consumption. Monthly occupancy variations for 2018 and 2019 are presented in Figure 11. From Figure 10 and Figure 11, it can be seen that the relationship between energy consumption and occupancy rate appears to be irregular which means that the increase of occupancy rate is not followed by the increase of energy use.

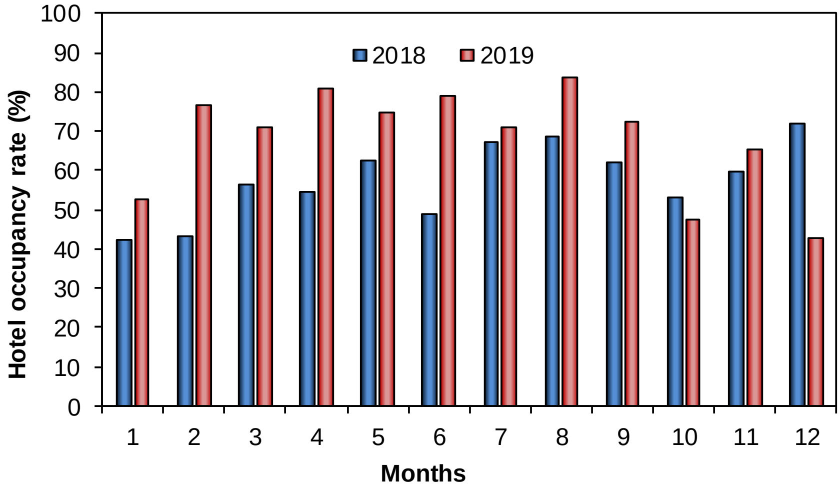


Fig. 11. Monthly occupancy rate of the hotel 2018 and 2019

In 2019, monthly and annual average occupancy rate was greater than 2018. However, the electricity consumption in 2019 was lower than in 2018. This is due to the presence of another parameter that can have a strong influence on electricity consumption, that is the usage of convention center. In 2018, there were many events, meetings, seminars and conferences that were intensive using convention center but most of the participants did not stay in the hotel. Convention center is one of the hotel facilities with intensive use of electrical energy, specifically for AC systems and lightings. Figure 10 and Figure 11 have illustrated that intensive use of the convention center can boost overall energy use of the hotel even the guestroom occupancy rate decreases.

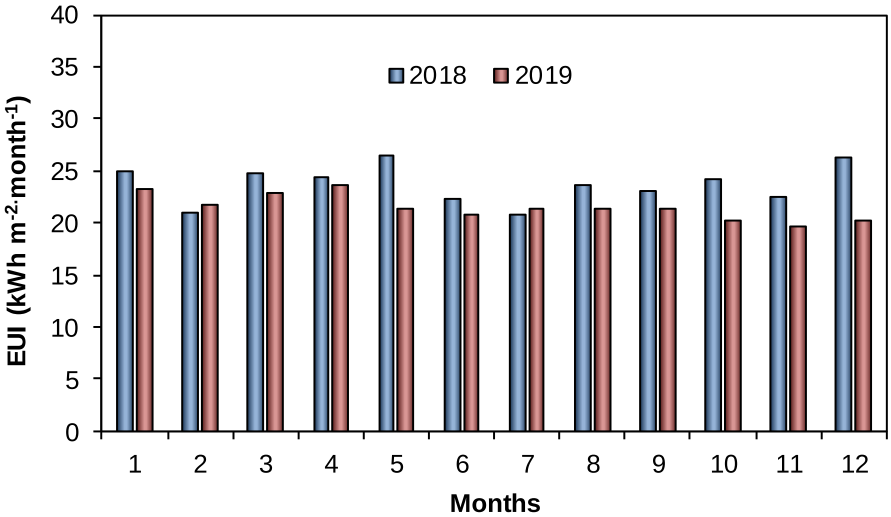


Fig. 12. Energy use intensity (EUI) of the hotel for two-year period

Furthermore, the energy performance parameters of the hotel are evaluated using EUI (Energy Use Intensity), which is calculated based on the ratio of energy consumption (kWh) to the conditioned floor area (m^2) within a certain period of time per month or per year. The EUI monthly variation of the hotel for 2018 and 2019 is illustrated in Figure 12. From the monthly EUI, it can then be determined that the annual EUIs for year 2018 and 2019 are 284.48 and 257.61 (kWh m^{-2} $year^{-1}$) respectively.

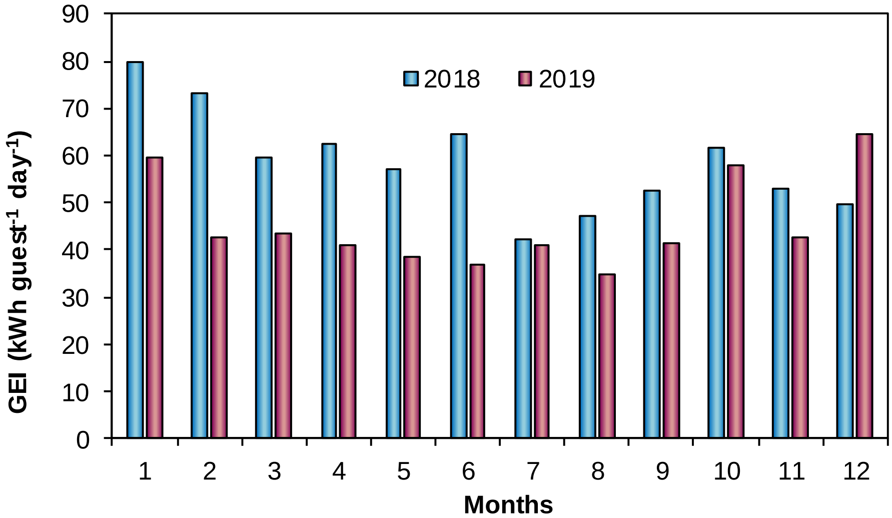


Fig. 13. Guest energy intensity (GEI) for the year 2018 and 2019

Another parameter that is more appropriate to describe the energy performance of the hotel industry without the need for a conditioned hotel building floor area is *GEI* (Guest Energy Intensity). *GEI* is a parameter that shows energy consumption (kWh) per number of guests staying (guest night). *GEI* monthly variations for 2018 and 2019 are presented in Figure 13. Annual *GEI* for 2018 and 2019 were obtained as low as 58.56 and 45.38 (kWh $guest^{-1}$ $night^{-1}$).

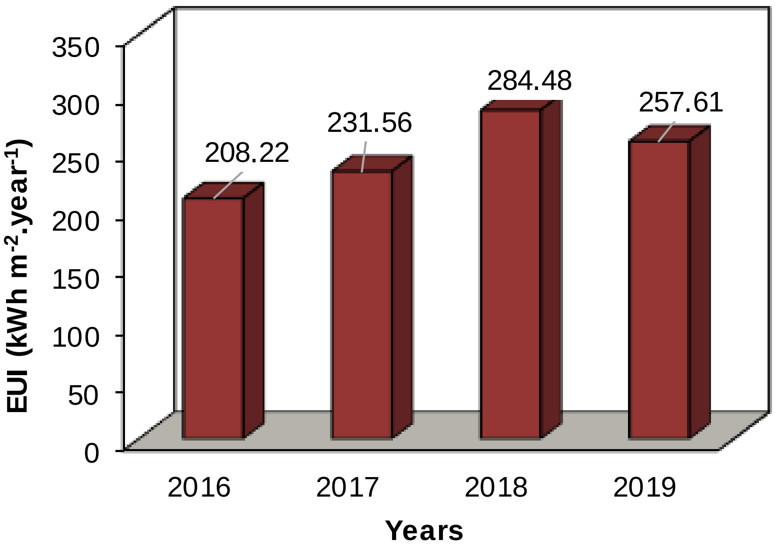


Fig. 14. Energy use intensity of the hotel from 2016 up to 2019

The change of EUI and GEI of the hotel from 2016 to 2019 are illustrated as shown in Figure 14 and Figure 15. From the figures, it can be seen that there was an increase in EUI and GEI proportionally from 2016 to 2018, then a decrease in 2019. The increase in hotel energy consumption from 2016 to 2018 was mainly due to an increase in occupancy rates and an increase in the number of events at the convention center. However, the reduction of electricity consumption in 2019 was mainly due to less intensive use of the convention center.

Moving the outdoor unit position to a better elevation level for AC systems of Group I in Building-1, which was conducted in 2017, did not have much effect on the decrease in energy consumption, but provides cooling capacity improvements compared to cooling capacity in previous mounting methods.

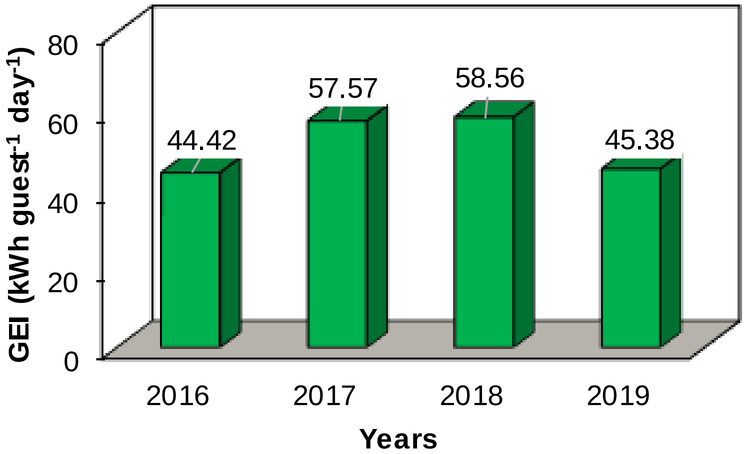


Fig. 15. Four-year guest energy intensity of the hotel

When compared with benchmarks as presented in Table 3 for *GEI*, the energy position or status of the hotel can be described as follows: based on the GEI benchmark (Table 3), which is a parameter commonly used for city hotels, the hotel is a hotel in the category of "High GEI rating" or "wasteful energy" with an annual *GEI* is above 43 (kWh guest^{-1} night^{-1}) in the hotel class with number of guestrooms falls in the range from 101 up to 200. Energy saving measures are urgently needed by hotel management to lower energy consumption to a level that is not wasteful of energy.

Table 3
GEI benchmark for hotels [53]

GEI Rating	Hotel size (number of guestrooms) 0-50	51-100	101-200	>200
High	118	87	43	50
Average	43	44	32	34
Low	12	18	25	22

GEI = Guest energy intensity (kWh guest^{-1} night^{-1})

3.3 Maintenance and Repair

The operation of a split AC system is relatively simple. In general, the operating system is equipped with controls that regulate the operation of the AC system based on the attainment of room air temperature. The controller automatically responds based on room air temperature and turn off the outdoor unit. Guestroom air temperature can be adjusted through the control system. Based on observations in the guestrooms, it is found that the AC setting has been setting at 18 °C. This temperature setting is considered too low. According to several published studies, it shows that room temperature settings can affect energy consumption of the AC system. Every 1 °C decrease in room temperature setting can increase energy consumption by 3% until 6% [47].

Maintenance of the AC systems carried out by the engineering department of the hotel has been well documented. For most of the AC systems, regular maintenance which includes cleaning evaporator and condenser coils has been carried out regularly and scheduled every 3 to 6 months.

Repairs that carried out for every AC system have also been recorded. Repairs involve insufficient refrigerant charge, water condensation on the refrigerant pipe surfaces and compressor replacement.

Regarding the maintenance of indoor units of the AC systems in Building-1, the hotel management confirmed that it was difficult to carry out maintenance due to poor access. It takes 2-3 technicians and a minimum of three days to perform cleaning of the evaporator coil. This means that during the maintenance process the guestrooms cannot be sold. Most of the time is spent for establishing maintenance access to the evaporator coil. This indicates that regular maintenance cannot be done regularly and consequently provides adverse effects that can decrease AC system performance such as dirty evaporator, low load, ice blocking, water dripping from indoor units due to melting ice blocking, and low cooling capacity. Additionally, the evaluation also showed that selection and installation of indoor unit of AC systems in Building-1 did not consider maintenance and repair aspects and results in very expensive and time-consuming regular maintenance.

3.4 Compressor Failure

The most worrying problem that occurs in the hotel is the early damage of the compressor in relatively large and continuous quantities. The problem began to arise after the hotel operated approximately 2 up to 3 years. Compressor damage usually begins with various symptoms, such as no cooling effect, tripping overload relay, noisy compressor, and jammed compressor. The problem intensively occurred on the AC systems installed in Building-1. In 2017 alone, there were 22 compressor replacements out of 90 AC units installed in Building-1 due to compressor faulty. This is accounting for more than 24%. Detailed of compressor replacements are given in Table 4.

Table 4
Compressor replacement by year, building and floor

Building Name	2017	2018	2019	Total
Building-1(Hotel building)				
Floor-1	4	2	4	10
Floor-2	4	3	4	11
Floor-3	6	8	2	16
Floor-4	5	2	3	10
Floor-5	3	2	2	7
Sub-total	22	17	15	54
Building-2 (Residence building)				
Floor-1	0	1	1	2
Floor-5	0	0	2	2
Sub-total	0	1	3	4
Building-3 (Residence building)				
Floor-1	0	4	0	4
Sub-total	0	4	0	4
Building-4 (Residence building)				
Floor-1	0	0	1	1
Floor-2	0	3	5	8
Floor-5	0	0	1	1
Sub-total	0	3	6	9
Convention Center	0	1	0	1
Toilet and Office	0	0	4	4
Sub-total	0	1	4	5
Grand total				76

Based on the compressor replacement data presented in Table 4 together with observation results and maintenance records, it can be summarized that

i. Number of damaged compressors for AC systems in Building-1 is very high. More than 54 compressors out of 90 total existing AC systems have been damaged. It is about 60% of AC systems have experienced compressor replacements;
ii. Compressor failure in Building-1 began to occur since 2017, whilst economic life of a compressor or split AC system is 10 years (maximum 15 years) [49]. This means compressors have been damaged far below their service life;
iii. Compressor damage in Buildings-2, 3, and 4 as well as convention center including offices also occurred but it was relatively small compared to Building-1 with a ratio of 5-12% of the total number of AC systems installed in each building. This occurred is mainly due to dirty condenser especially for AC systems with poor access for maintenance as shown in Figure 6;
iv. Overall number of compressors that were damaged in the last 3 years were 76 out of 329 AC systems or around 23.1%;
v. Installation of AC units in Building-1 is in principle different from AC system installation in other buildings, specifically the elevation of the outdoor unit is higher than the elevation of the indoor unit, with pipe lengths and elevation differences far exceed the manufacturer's recommendations. This installation type adopted high suction pipe risers but without oil trap at all. This inevitably prevents oil draining back to the compressor and leading to compressor oil problems. Finally, it can damage the compressor. Additionally, excessive amount of oil inside evaporator can reduce its cooling capacity.

Rearranging the outdoor unit position to a better elevation level for AC systems of Group I in Building-1 has been conducted in 2017. The new arrangement includes the elevation of the outdoor unit is lower than the elevation of the indoor unit. The pipe lengths and elevation differences are within the manufacturer's recommendations. The new arrangement did not have much effect on the decrease in energy consumption, but it can provide better cooling capacity and reduce compressor damage compared to previous installation methods as illustrated in Table 4.

Significant number of damaged compressors is contrary to the recommendations of the ASHRAE Handbook [54] which recommends that vapor compression AC systems are designed to avoid the need for compressor replacement. The recommendation provides guidelines for selection and installation of AC systems have to be properly designed in order to minimize the possibility of early damage to the compressor.

Early compressor replacement certainly adds to the maintenance and repair costs of the AC systems significantly because the budget of replacing a compressor can be as high as half the price of a new split AC system. Therefore, a proper AC system selection and installation that are suitable for building construction, cooling load demand and access for regular maintenance can ensure excellent AC system performance and reduce energy consumption of the hotel as a whole system.

4. Conclusions

In this appraisal, assessing the energy performance of AC systems applied for a city hotel located in Bali, Indonesia has been carried out. Related to energy performance of the AC system in the hotel, it was found that there were several weaknesses in the installation and components selection of the AC systems which include: (i) Some AC systems with their outdoor units installed on the rooftop of the hotel building with very long pipe span and suction pipe risers far exceeding that recommended by the manufacturer. The worse was the riser pipes were not equipped with oil trap. This inevitably prevents oil back to the compressor and have damaged system compressors in three years of about

54 (accounted for 60%) from 90 AC systems with the same method of installations. Most of the oil is trapped in the evaporator itself. Excessive trapped oil in the evaporator can also influence heat transfer and reduce cooling capacity of the AC system; (ii) Some AC systems were also found to have their indoor units with poor access to carry out maintenance. This results in regular maintenance cannot be done and consequently provides adverse effects that can decrease AC system performance.

Energy performance of the AC system which finally affect the energy performance of the city hotel can be summarized as follows: system efficiency index (*SEI*) of all evaluated AC systems in the hotel are found to have excellent *SEI* grade with *SEI* values ranging from 51.9 to 55.0% which are more than 40%. The results have also confirmed that in term of energy consumption, the AC systems of the hotel buildings, in general, still consume energy in the normal range. However, they have lower COP and lower cooling capacity than specified by manufacturer. Energy consumption profile of the hotel in the last two years has also shown that energy status of the hotel, based on Gust Energy Intensity (GEI), can be grouped in the hotels with “High GEI rating” or “wasteful energy” of annual GEI is above 43 (kWh guest^{-1} night^{-1}).

This assessment has shown that system selection, installation method and regular maintenance have also a very important role on the AC system performance applied for city hotel. Opportunities for energy efficiency improvement and saving electricity costs for the hotel can be improved through modification of AC system installation and replacement of the improper AC system which is more suitable to the hotel conditions and implementation of energy saving measures by hotel management.

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References

[1] Karali, Nihan, Nihar Shah, Won Young Park, Nina Khanna, Chao Ding, Jiang Lin, and Nan Zhou. "Improving the energy efficiency of room air conditioners in China: Costs and benefits." *Applied Energy* 258 (2020): 114023. https://doi.org/10.1016/j.apenergy.2019.114023

[2] Vourdoubas, John. "Energy consumption and use of renewable energy sources in hotels: A case study in Crete, Greece." *Journal of Tourism and Hospitality Management* 4, no. 2 (2016): 75-87. https://doi.org/10.15640/jthm.v4n2a5

[3] Gaglia, Athina G., Evangelos N. Dialynas, Athanassios A. Argiriou, Effie Kostopoulou, Dimitris Tsiamitros, Dimitris Stimoniaris, and Konstantinos M. Laskos. "Energy performance of European residential buildings: Energy use, technical and environmental characteristics of the Greek residential sector-energy conservation and CO_2 reduction." *Energy and Buildings* 183 (2019): 86-104. https://doi.org/10.1016/j.enbuild.2018.10.042

[4] Amasyali, Kadir, and Nora M. El-Gohary. "A review of data-driven building energy consumption prediction studies." *Renewable and Sustainable Energy Reviews* 81 (2018): 1192-1205. https://doi.org/10.1016/j.rser.2017.04.095

[5] Kishore, Ravi Anant, Marcus VA Bianchi, Chuck Booten, Judith Vidal, and Roderick Jackson. "Optimizing PCM-integrated walls for potential energy savings in US Buildings." *Energy and Buildings* 226 (2020): 110355. https://doi.org/10.1016/j.enbuild.2020.110355

[6] Ma, Hongting, Na Du, Shaojie Yu, Wenqian Lu, Zeyu Zhang, Na Deng, and Cong Li. "Analysis of typical public building energy consumption in northern China." *Energy and Buildings* 136 (2017): 139-150. https://doi.org/10.1016/j.enbuild.2016.11.037

[7] Allouhi, Amine, Youness El Fouih, Tarik Kousksou, Abdelmajid Jamil, Youssef Zeraouli, and Youssef Mourad. "Energy consumption and efficiency in buildings: current status and future trends." *Journal of Cleaner Production* 109 (2015): 118-130. https://doi.org/10.1016/j.jclepro.2015.05.139

[8] Alonso, Serafín, Antonio Morán, Miguel Ángel Prada, Perfecto Reguera, Juan José Fuertes, and Manuel Domínguez. "A data-driven approach for enhancing the efficiency in chiller plants: A hospital case study." *Energies* 12, no. 5 (2019): 827. https://doi.org/10.3390/en12050827

[9] He, Bao-Jie. "Towards the next generation of green building for urban heat island mitigation: Zero UHI impact building." *Sustainable Cities and Society* 50 (2019): 101647. https://doi.org/10.1016/j.scs.2019.101647
[10] Carpio, Manuel, Álvaro González, Marcelo González, and Konstantin Verichev. "Influence of pavements on the urban heat island phenomenon: a scientific evolution analysis." *Energy and Buildings* 226 (2020): 110379. https://doi.org/10.1016/j.enbuild.2020.110379
[11] Meng, Fanchao, Jun Guo, Guoyu Ren, Lei Zhang, and Ruixue Zhang. "Impact of urban heat island on the variation of heating loads in residential and office buildings in Tianjin." *Energy and Buildings* 226 (2020): 110357. https://doi.org/10.1016/j.enbuild.2020.110357
[12] Zhou, Yuyu, Jiyong Eom, and Leon Clarke. "The effect of global climate change, population distribution, and climate mitigation on building energy use in the US and China." *Climatic Change* 119, no. 3 (2013): 979-992. https://doi.org/10.1007/s10584-013-0772-x
[13] Santamouris, Matheos, Constantinos Cartalis, Afroditi Synnefa, and Dania Kolokotsa. "On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings-A review." *Energy and Buildings* 98 (2015): 119-124. https://doi.org/10.1016/j.enbuild.2014.09.052
[14] Li, Xiaoma, Yuyu Zhou, Sha Yu, Gensuo Jia, Huidong Li, and Wenliang Li. "Urban heat island impacts on building energy consumption: A review of approaches and findings." *Energy* 174 (2019): 407-419. https://doi.org/10.1016/j.energy.2019.02.183
[15] Palme, M., L. Inostroza, G. Villacreses, Andrea Lobato-Cordero, and C. Carrasco. "From urban climate to energy consumption. Enhancing building performance simulation by including the urban heat island effect." *Energy and Buildings* 145 (2017): 107-120. https://doi.org/10.1016/j.enbuild.2017.03.069
[16] Lima, Izabella, Veridiana Scalco, and Roberto Lamberts. "Estimating the impact of urban densification on high-rise office building cooling loads in a hot and humid climate." *Energy and Buildings* 182 (2019): 30-44. https://doi.org/10.1016/j.enbuild.2018.10.019
[17] Rashid, Syed Aftab, Zeeshan Haider, SM Chapal Hossain, Kashan Memon, Fazil Panhwar, Momoh Karmah Mbogba, Peng Hu, and Gang Zhao. "Retrofitting low-cost heating ventilation and air-conditioning systems for energy management in buildings." *Applied Energy* 236 (2019): 648-661. https://doi.org/10.1016/j.apenergy.2018.12.020
[18] Carlson, Kaitlin, and Kim D. Pressnail. "Value impacts of energy efficiency retrofits on commercial office buildings in Toronto, Canada." *Energy and Buildings* 162 (2018): 154-162. https://doi.org/10.1016/j.enbuild.2017.12.013
[19] Lidelöw, Sofia, Tomas Örn, Andrea Luciani, and Agatino Rizzo. "Energy-efficiency measures for heritage buildings: A literature review." *Sustainable Cities and Society* 45 (2019): 231-242. https://doi.org/10.1016/j.scs.2018.09.029
[20] Galatioto, A., R. Ricciu, T. Salem, and E. Kinab. "Energy and economic analysis on retrofit actions for Italian public historic buildings." *Energy* 176 (2019): 58-66. https://doi.org/10.1016/j.energy.2019.03.167
[21] Ding, Yan, Qiaochu Wang, Zhaoxia Wang, Shuxue Han, and Neng Zhu. "An occupancy-based model for building electricity consumption prediction: A case study of three campus buildings in Tianjin." *Energy and Buildings* 202 (2019): 109412. https://doi.org/10.1016/j.enbuild.2019.109412
[22] Mokhtari, Fatiha, Djaffar Semmar, Mourad Chikhi, Nachida Kasbadji Merzouk, and Soumia Oukaci. "Investigation of The Improvement Building Envelope Impact on Energy Consumption Using Energy Audit." In *MATEC Web of Conferences*, vol. 307, p. 01031. EDP Sciences, 2020. https://doi.org/10.1051/matecconf/202030701031
[23] Alkhateeb, Enas, and Bassam Abu-Hijleh. "Potential for retrofitting a federal building in the UAE to net zero electricity building (nZEB)." *Heliyon* 5, no. 6 (2019): e01971. https://doi.org/10.1016/j.heliyon.2019.e01971
[24] Liu, Zhijian, Di Wu, Junyang Li, Hancheng Yu, and Baojie He. "Optimizing building envelope dimensions for passive solar houses in the Qinghai-Tibetan region: window to wall ratio and depth of sunspace." *Journal of Thermal Science* 28, no. 6 (2019): 1115-1128. https://doi.org/10.1007/s11630-018-1047-7
[25] Djamila, Harimi, Mariani Rajin, and Ahmad Nurfaidhi Rizalman. "Energy efficiency through building envelope in Malaysia and Singapore." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 46, no. 1 (2018): 96-105.
[26] Kurekci, Nuri Alpay. "Determination of optimum insulation thickness for building walls by using heating and cooling degree-day values of all Turkey's provincial centers." *Energy and Buildings* 118 (2016): 197-213. https://doi.org/10.1016/j.enbuild.2016.03.004
[27] Awang, Norati Artini, Haslinda Mohamed Kamar, and Nazri Kamsah. "Energy saving potential of an air-conditioner-ice thermal storage (AC-ITS) system." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 31, no. 1 (2017): 1-10.
[28] Park, Kwon Sook, and Mi Jeong Kim. "Energy demand reduction in the residential building sector: a case study of Korea." *Energies* 10, no. 10 (2017): 1506. https://doi.org/10.3390/en10101506
[29] He, Yingdong, Nianping Li, Hui Zhang, Yangli Han, Jiamin Lu, and Linxuan Zhou. "Air-conditioning use behaviors when elevated air movement is available." *Energy and Buildings* 225 (2020): 110370. https://doi.org/10.1016/j.enbuild.2020.110370

[30] Abdullah, Mohammad Kamil, and Mohd Hafiz Mohamad. "Building Energy Performance: A Case Study at G2 Building UTHM." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 50, no. 2 (2018): 161-169.
[31] Bienvenido-Huertas, David, Daniel Sánchez-García, Alexis Pérez-Fargallo, and Carlos Rubio-Bellido. "Optimization of energy saving with adaptive setpoint temperatures by calculating the prevailing mean outdoor air temperature." *Building and Environment* 170 (2020): 106612. https://doi.org/10.1016/j.buildenv.2019.106612
[32] Liu, Lijun, Quan Zhang, John Zhai, Chang Yue, and Xiaowei Ma. "State-of-the-art on thermal energy storage technologies in data center." *Energy and Buildings* 226 (2020): 110345. https://doi.org/10.1016/j.enbuild.2020.110345
[33] Sánchez-García, Daniel, Carlos Rubio-Bellido, Juan Jesús Martín del Río, and Alexis Pérez-Fargallo. "Towards the quantification of energy demand and consumption through the adaptive comfort approach in mixed mode office buildings considering climate change." *Energy and Buildings* 187 (2019): 173-185. https://doi.org/10.1016/j.enbuild.2019.02.002
[34] Ren, Zhengen, and Dong Chen. "Modelling study of the impact of thermal comfort criteria on housing energy use in Australia." *Applied Energy* 210 (2018): 152-166. https://doi.org/10.1016/j.apenergy.2017.10.110
[35] Suamir, I. Nyoman, I. Nyoman Gede Baliarta, Made Ery Arsana, and I. Putu Sastra Negara. "Condenser-Evaporator Approach Temperatures and their Influences on Energy Performance of Water Cooled Chillers." In *Proceeding of the 14th International Conference on QIR (Quality in Research)*, p. 428-433. August 10-13, 2015.
[36] Suamir, I. Nyoman, I. Baliarta, Made Ery Arsana, and I. Wayan Temaja. "The Role of Condenser Approach Temperature on Energy Conservation of Water Cooled Chiller." *Advanced Science Letters* 23, no. 12 (2017): 12202-12205. https://doi.org/10.1166/asl.2017.10602
[37] Tushar, Wayes, Tao Wang, Lan Lan, Yunjian Xu, Chathura Withanage, Chau Yuen, and Kristin L. Wood. "Policy design for controlling set-point temperature of ACs in shared spaces of buildings." *Energy and Buildings* 134 (2017): 105-114. https://doi.org/10.1016/j.enbuild.2016.10.027
[38] Chua, Kian Jon, Siaw Kiang Chou, W. M. Yang, and Jinyue Yan. "Achieving better energy-efficient air conditioning-a review of technologies and strategies." *Applied Energy* 104 (2013): 87-104. https://doi.org/10.1016/j.apenergy.2012.10.037
[39] Suamir, I. Nyoman, I. Nengah Ardita, and I. G. A. B. Wirajati. "Waste heat recovery from central AC system for hot water supply; a case study for hotel building application in Indonesia." *Advanced Science Letters* 23, no. 12 (2017): 12206-12210. https://doi.org/10.1166/asl.2017.10603
[40] Suamir, I. N., I. B. P. Sukadana, and M. E. Arsana. "Minimizing temperature instability of heat recovery hot water system utilizing optimized thermal energy storage." In *Journal of Physics: Conference Series*, vol. 953, no. 1, p. 012113. IOP Publishing, 2018. https://doi.org/10.1088/1742-6596/953/1/012113
[41] Opoku, Richard, Isaac Adjei Edwin, and Kofi A. Agyarko. "Energy efficiency and cost saving opportunities in public and commercial buildings in developing countries-the case of air-conditioners in Ghana." *Journal of Cleaner Production* 230 (2019): 937-944. https://doi.org/10.1016/j.jclepro.2019.05.067
[42] Guo, Siyue, Da Yan, Shan Hu, and Jingjing An. "Global comparison of building energy use data within the context of climate change." *Energy and Buildings* 226 (2020): 110362. https://doi.org/10.1016/j.enbuild.2020.110362
[43] Clarke, Leon, Jiyong Eom, Elke Hodson Marten, Russell Horowitz, Page Kyle, Robert Link, Bryan K. Mignone, Anupriya Mundra, and Yuyu Zhou. "Effects of long-term climate change on global building energy expenditures." *Energy Economics* 72 (2018): 667-677. https://doi.org/10.1016/j.eneco.2018.01.003
[44] Wang, Mengmeng, Xiaojun Liu, Hanliang Fu, and Baiyu Chen. "Scientometric of Nearly Zero Energy Building Research: A Systematic Review from the Perspective of Co-Citation Analysis." *Journal of Thermal Science* 28, no. 6 (2019): 1104-1114. https://doi.org/10.1007/s11630-019-1172-y
[45] D'Agostino, Delia, and Danny Parker. "A framework for the cost-optimal design of nearly zero energy buildings (NZEBs) in representative climates across Europe." *Energy* 149 (2018): 814-829. https://doi.org/10.1016/j.energy.2018.02.020
[46] Opoku, Richard, Eunice A. Adjei, Divine K. Ahadzie, and Kofi A. Agyarko. "Energy efficiency, solar energy and cost saving opportunities in public tertiary institutions in developing countries: the case of KNUST, Ghana." *Alexandria Engineering Journal* 59, no. 1 (2020): 417-428. https://doi.org/10.1016/j.aej.2020.01.011
[47] Muhammad, Jamilu Ya'U., Abdullahi Audu Adamu, Abdulkarim Mika'il Alhaji, and Yerima Yusif Ali. "Energy Audit and Efficiency of a Complex Building: A Comprehensive Review." *Engineering Science* 3, no. 4 (2018): 36-41.
[48] Lodi, Chiara, Vania Malaguti, Francesco Maria Contini, Luigi Sala, Alberto Muscio, and Paolo Tartarini. "University energy planning for reducing energy consumption and GHG emissions: the case study of a university campus in Italy." *International Journal of Heat and Technology* 35, no. 1 (2017): S27-S32. https://doi.org/10.18280/ijht.35Sp0104
[49] ASHRAE Handbook. *HVAC Systems and Equipment*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2019.

[50] ANSI/ASHRAE Standard 62.1. *Ventilation for Acceptable Indoor Air Quality*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2013.
[51] Lane, Anna-Lena, Jessica Benson, Lina Eriksson, and Per Fahlén. "Method and guidelines to establish System Efficiency Index during field measurements on air conditioning and heat pump systems." *SP Technical Research Institute of Sweden* (2014).
[52] Bell Jr, Arthur A. *HVAC: equations, data, and rules of thumb*. McGraw-Hill Education, 2007.
[53] IIEC. *Energy Efficiency Guidelines for Hotels in the Pacific*. International Institute for Energy Conservation, 2015.
[54] ASHRAE Handbook. *Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2017.