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RESEARCH ARTICLE | MAY 08 2023 Field and numerical evaluation on cooling and heating system alternatives for a five star hotel building towards energy conservation I. Nyoman Suamir ?; I. Made Rasta; Adi Winarta AIP Conference Proceedings 2706, 020104 (2023) https://doi.org/10.1063/5.0120247 ?? CrossMark View Export Online Citation Articles You May Be Interested In Site investigation on water cooled chiller plant for energy conservation and environmental impact reduction of a large shopping mall AIP Conference Proceedings (December 2019) Investigation on seasonal energy performance of residential AC systems using R-32 a low GWP refrigerant AIP Conference Proceedings (May 2023) The hotel benefits from the implementation of green hotel practices among Malaysian hotels AIP Conference Proceedings (November 2022) Downloaded from http://pubs.aip.org/aip/acp/article-pdf/doi/10.1063/5 .0120247/17411823/020104_1_5.0120247.pdf Field and Numerical Evaluation on Cooling and Heating System Alternatives for a Five Star Hotel Building Towards Energy Conservation I Nyoman Suamir1, a), I Made Rasta1, b) and Adi Winarta1, c) 1Department of Mechanical Engineering, Politeknik Negeri Bali, 80364, Indonesia a) Corresponding author: nyomansuamir@pnb.ac.id b) maderasta@pnb.ac.id c) adi.winarta@pnb.ac.id Abstract. The global contribution of hotel buildings to energy consumption continues to increase. Among hotel services, the energy consumed by cooling and heating systems can exceed 50% of the total energy use. For the purpose of energy conservation, five cooling and heating systems have been investigated. The aim is to investigate the most energy efficient cooling and heating system which can completely satisfy cooling and heating demands of a five star hotel building towards energy conservation. The study was based on field measurement and numerical analyses of cooling and heating systems. Data were processed and analyzed by using spread sheet and EES (Engineering Equations Solver) programs. The results showed that a cooling and heating system comprised a centrifugal water cooled chiller R-134a and two units heat pump was the most energy efficient system. The system also has the lowest CO2 emissions, and the most economic viable system with payback period less than 1.5 years. The results of the study can provide flexible alternatives to the hotel building management and consultant especially in tropical countries in determining the most suitable cooling and heating system for energy conservation measure. INTRODUCTION Rising world energy consumption and fears of energy shortages, global warming, environmental degradation a pressing global problem [1]. Global warming is caused by greenhouse gas (GHG) emissions, mainly CO2 emissions [2]. As a result, government agencies develop regulations to reduce greenhouse gas (GHG) emissions. The high energy consumption produced by the building sector is one of the main causes of energy emissions [3]. The building sector accounts for more than 40% of global energy consumption [4]. The lack of energy performance of most buildings affects its high energy use [5], especially buildings designed before applying standards on energy efficiency [6]. Demand for building services and comfort levels, ensures an upward trend in energy demand can continue in the future [7]. Simultaneously people spend more than 85% in the building [8]. For this reason, energy efficiency in buildings is currently the main objective of energy policy at regional, national and international levels. Among building services, the growth in energy use of HVAC systems is very significant (50% of building consumption) [9]. Increasing the difference between world energy supply and demand, the international community is now focused on increasing energy efficiency. To improve energy efficiency the country must promote energy efficiency through technological advancements, reduce energy waste and inefficiencies caused by imperfect management [10]. Energy efficiency work is significantly important to save energy and maintain sustainable economic growth [11,12]. The contribution of buildings, including hotel buildings, uses 50% of energy in general or 70% of electricity in total consumption in Indonesia, making it the largest energy user even exceeding the industrial and transportation sectors. In terms of energy use the Air Conditioning System in buildings consumes 65% of the total energy use in hotel buildings [13]. The hotel sector itself is developing very rapidly in Indonesia and tourist visits to Bali continue to increase. Air conditioning plays a very important role to maintain thermal comfort in the indoor environment, 3rd Borobudur International Symposium on Science and Technology 2021 AIP Conf. Proc. 2706, 020104-1–020104-7; https://doi.org/10.1063/5.0120247 Published by AIP Publishing. 978-0-7354-4447-8/$30.00 especially for hot and humid climates. Energy consumed by heating, ventilation and air conditioning (HVAC) in tropical climates can exceed 50% of the total building energy consumption [13] and 30-50% in China [14]. This is the biggest part of hotel building energy consumption. Therefore, there is tremendous potential to improve the overall efficiency of air conditioning systems in hotel buildings. The biggest electricity usage in hotel buildings is 70-80% for chiller operations. Chiller is a major component of HVAC systems. Hotel energy consumption and operating costs can be reduced by optimizing the chillers operational parameters [15,16,17]. Management of an efficient multi-chiller system is very challenging [18]. The overall energy efficiency of the chiller system can have a major impact using the chiller sequence [19]. It is wise practice to use coolers that have the best efficiency on demand compared to other coolers, which use more energy [20,21]. Energy demand for air conditioning can increase rapidly in the 21st century. [22]. Higher outdoor temperatures impacting climate change affect cooling energy in terms of higher room temperatures and more stringent thermal comfort requirements. In addition, the impact of climate change on air conditioning is expected to cause energy demand to surge by 72%. The biggest consumers of energy related to air conditioning can come from developing countries. The big increase is postulated to be in South Asia because energy demand for air conditioning can increase by around 50% due to climate change [23]. Improving energy efficiency in hotel buildings is currently the main objective of energy policy at regional, national and international levels. Among building services, the growth in energy use of HVAC systems is very significant [24]. The high energy consumption in this hotel building contributed to the high operational costs of the hotel (by 25-30%), in addition to a substantial contribution to greenhouse gas emissions and global warming. To encourage wider implementation of energy efficiency, to support the Government of Indonesia's commitment to reduce Greenhouse Gas (GHG) emissions by 26% by 2020 [13]. Energy saving is one smart solution to be applied to hotels. Therefore, actions from the building sector to mitigate and adapt to climate change are very important to reduce building energy consumption and GHG emissions [25]. The hotel has one central plant for its cooling system which comprises three water cooled chillers. Hotel is a resorts and villas hotel and is situated on 170.000 m2 area. Therefore, hotel building services also covers a very large area. Facility services of the hotel use two energy types which include electricity and diesel fuel. Electricity is the main energy source of the hotel accounting for 88% and relatively small consumption on diesel fuel of about 12% of total energy use. The electrical energy is used for AC system, refrigeration, lighting, pumping system and facility equipment. For large area hotel, the Air Conditioning, Pumping and Lighting systems become facilities with significant energy use. For energy management purposes, these facilities need to be carefully designed and monitored. Saving Energy consumption and thermal comfort in the room must be analyzed and always improved in every retrofit of the hotel building HVAC system [26]. By discovering potential energy savings contained in the energy investigate of the HVAC system at this hotel, it is hoped that it can help more efficient use of energy in hotels and reduce CO2 emissions to the environment for sustainable development. METHOD This study was based on experimental and numerical analyses of cooling and heating system of a case study hotel which is a five-star hotel located in Bali-Indonesia as one of tropical countries. Experimental method was applied to obtain data from the existing systems, while numerical analysis was used to simulate energy and temperature performance of the integrated system. Tests were conducted on the existing cooling and heating system for five days continuously in order to obtain daily data of cooling system (chiller) performance and load factor variation of the chillers operation. Ambient temperature and relative humidity of the tests varied from 26 °C to 31 °C and from 76% to 88% RH respectively. The analyses in this study were based on secondary data and information obtained from hotel's representatives and primary data which were directly measured at the cooling and heating systems. Feasibility analyses were established in a spread sheet program and were based on hourly part load operation. Part load data was obtained from the data log sheet and in combination with occupancy rate data of the hotel. Hourly part load operation of the cooling system is shown in Figure 1 and monthly average of hotel occupancy rate two years can be seen in Figure 2. The feasibility analyses include energy performance, environmental impact and economic viability of system alternatives. Energy performance of the chiller stated as COP (Coefficient of Performance) is calculated from the chiller cooling load (Qeva) and compressor power (Wcom) as expressed in Eq.(1) (the units of Qeva and Wcom in kW). Q!"# $COP = W$ $%& (1) Other performance parameter used is Chiller efficiency (CE) in terms of the full-load kW per ton of refrigeration (kW/TR). The CE is determined by using Eq. (2). $W$$%& $(inkW)$ $CE = Q$!"# $(inTR)$ (2) 100 90 80 Part Load (%) 70 60 50 40 30 20 10 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 Hours FIGURE 1. Hourly part load operation of the chiller in hotel at 100% occupancy rate Direct and indirect environmental impacts of the chiller due to refrigerant leakage and recovery as well as energy use were estimated based on BS EN 378-1 Standard [27]. CO2 emissions factor (β) of electricity generation in Indonesia was based on grade emissions factor of Java-Madura-Bali region of 0.84 tCO2e./MWh [28]. This value was published by Indonesia Government in the year of 2014. 100% 90% 80% Occupancy rate 70% 60% 50% 40% 30% 20% 10% 0% 1 2 3 4 5 6 7 8 9 10 11 12 Months FIGURE 2. Occupancy rate (two years average) of hotel for analyses Existing Cooling and Heating Systems Hotel has one central plant for its air conditioning system which comprises three water cooled chillers. The chillers utilize centrifugal compressors with cooling capacity of 650 TR each. The chiller was charged refrigerant R-134a. Due to the hotel building services covers a very large area, the air conditioning system chosen for the hotel comprises two chilled water loops: primary and secondary loops. Chilled water in each loop is circulated by primary pumps and secondary pumps for primary and secondary loops respectively. Operation of the Cooling and Heating Systems The operation of the water-cooled chillers is supported by cooling towers, chilled water pumps, and cooling water pumps and is semi-manually controlled by the operation staffs. The chillers can be operated, controlled and monitored from the control room. However, the chillers cannot automatically adapt their cooling capacity to satisfy the cooling demand. To adjust the cooling capacity of the chillers a manual setting up is required. Manual control is certainly less responsive compared with fully automatic control system and could cause inefficient operation. Automatic controller can respond based on entering chilled water temperature for chiller and chilled pump operation and entering cooling water temperature for cooling towers and cooling pumps operation. Automatic control system is one way to improve overall energy performance of the air conditioning system. Energy Consumption Overview Facility services of the hotel use two energy types which include electricity and diesel fuel. Electricity is the main energy source of the hotel accounting for 88% and relatively small consumption on diesel fuel of about 12% of total energy use. Total energy consumption for facility services based on energy data is 16,812.54 MJh/year. The electrical energy is used for AC system, refrigeration, lighting, pumping system and facility equipment. For large area hotel, the Air Conditioning, Pumping and Lighting systems become facilities with significant energy use. For energy management purposes, these facilities need to be carefully designed and monitored. Electrical energy consumption of the hotel was calculated to be 14,815 MJh/year. The energy use intensity (EUI) of the hotel was to be 308.58 kWh/m2/year. The EUI of the hotel is almost as low as energy use intensity for ASEAN countries recommended by APEC of 300 kWh/m2/year. This achievement indicates that hotel management has put a great effort in energy management to get down the EUI. Present energy saving plan is certainly necessary to be implemented continuously to maintain or squeeze further down the energy consumption. Chiller and Hot Water System Alternative The cooling system at the case study hotel uses 3 water cooled centrifugal chillers of total cooling capacity 1950 TR. Most of the time only one chiller is in operation. Two chillers are quite new about 4 to 8 years old but another one is quite old with energy efficiency of 1.3 kW/TR. While the existing hot water supply comprises two diesel fuel fired steam boilers and hot water storages with calorifiers. The hot water of 50-55 °C is produced from the calorifiers in the hot water (HW) storage tanks. This is an inefficient way to produce hot water. Heat and temperature losses occur during the process from boiler to the calorifier. This study and analysis is one stage of the improvement of the cooling and heating system of the hotel. The analysis evaluates possible alternatives that can be implemented for cooling and heating systems of the hotel. There are 4 chillers and hot water system alternatives have been analyzed, namely: • Alternative-1: a 650 TR centrifugal chiller R-134a to be integrated with two units heat pump of @364 kW heating capacity. • Alternative-2: a 650 TR centrifugal chiller R-123 to be integrated with two units heat pump of @364 kW heating capacity. • Alternative-3: a 750 TR screw modular chiller of 3 x 250 TR modules with heat recovery to be integrated with 1 unit heat pump of 364 kW heating capacity for back up. • Alternative-4: a 650 TR screw modular chiller of 2 x 200 TR modules and 1 x 250 TR module with heat recovery to be integrated with 1 unit heat pump of 364 kW heating capacity for back up. RESULTS AND DISCUSSION Energy and Environmental Analyses Table 1 shows the summary of annual energy performance and environmental impact analyses of chiller and hot water system alternatives. The analysis results of the existing systems are also presented. It can be seen that annual efficiency of the existing Chiller is very low with energy consumption of 1.26 kW per ton refrigeration. Replacing this chiller with more efficient centrifugal chiller can improve energy performance of the hotel. In term of energy performance and environmental impact, system of Alternative-2 consumes the lowest energy and responsible for the lowest CO2 emission to the environment. The chiller, however, uses refrigerant R-123 which has ODP of 0.02. The phase out of refrigerant R-123 for Indonesia will be in 2040. This energy efficient chiller will still be cost-effective for 19 years operation, if the system is installed in 2021. The seconds best energy and environmental performance alternative is system of Alternative-1. This alternative consumes 2,493 MWh electricity per year and responsible for 2,069 ton-CO2/year with zero ODP. TABLE 1. Summary of energy and environmental analysis of cooling and heating system alternatives No Parameters Existing Cooling and heating System Alternatives system Alt-1 Alt-2 Alt-3 Alt-4 1 Detailed Energy Performance Seasonal COP 2.79 6.32 Seasonal efficiency (kW/TR) 1.26 0.56 Seasonal part load (%) 64.12 64.12 Seasonal electricity for Chiller (MWh) 4,595 2,012 Seasonal electricity for hot water (MWh) - 481 Total seasonal electricity (MWh) 4,595 2,493 Seasonal diesel fuel for hot water (MWh) 1,997 - 2 Detailed Environmental Impact 6.49 5.21 0.54 0.67 64.12 55.57 1,973 2,472 481 156 2,454 2,628 - - 5.20 0.68 63.95 2,486 156 2,642 - Indirect impact from electricity (ton-CO2/year) 3,285 1,479 1,411 1,767 1,777 Direct impact from refrigerant (ton-CO2/year) 97 97 7 149 129 Indirect impact from fuel (ton-CO2/year) 533 Total impact (ton-CO2/year) 3,926 1,536 1,418 1,917 1,906 Ozone Depleting Potential (ODP) 0.00 0.00 0.02 0.00 0.00 Alt-1 = Alternative-1; Alt-2 = Alternative-2; Alt-3 = Alternative-3; Alt-4 = Alternative-4 of the cooling and heating systems Economic Analysis Economic viability of chiller and hot water system alternatives is shown in Table 2. From the table, it can be seen that system Alternative-2 can provide the lowest payback period of 1.20 years compared with existing system. This alternative has high energy performance and low environmental impact. TABLE 2. Summary of economic viability of cooling and heating system alternatives No Parameters Cooling and heating System Alternatives Alt-1 Alt-2 Alt-3 Alt-4 1 Detailed cost components Cost on investment (MRp) 6,156 Cost on chiller operational (MRp/year) 2,501 Cost on hot water supply (MRp/year) 490 Total cost of operational (MRp/year) 2,991 2 Detailed cost saving Based on the existing chiller (MRp/year) 5,007 3 Payback period Based on the existing chiller (years) 1.23 4 Total investment & cost of operational (MRp) In 4 years, equipment application 18,124 In 20 years, equipment lifetime 65,996 MRp = million rupiahs 6,041 2,456 490 2,946 5,052 1.20 17,829 64,978 5,754 3,153 159 3,314 4,684 1.23 19,013 72,048 4,517 3,132 159 3,291 4,707 0.96 17,684 70,347 For long term application (more than 10 years) the alternative is economically more viable than other alternatives. As can be seen in Table 1 and 2, system Alternative-1 is also feasible for the hotel. Its energy performance and economic viability is slightly below the Alternative-2. Its environmental impact is slightly higher than alternative-2 but it has zero ODP. Based on the analysis results and energy conservation purposes, it can be recommended two most feasible chiller and hot water supply system which can be implemented in the case study hotel i.e.: Alternative-2 and Alternative-1. The complete priority order of the system alternatives can be described as below: • The first priority: Alternative-2 with justifications: The most economic viable system for lifetime application (more than 15 years); The lowest annual operational cost; Payback period 1.20 years; The most efficient system; The lowest energy consumption; Responsible for the second lowest CO2 emissions, and Responsible for 0.02 ODP, but phase out will be in 2040. • The second priority: Alternative-1, justifications: The second most economic viable system for lifetime application (more than 15 years); The second lowest annual operational cost; Payback period 1.23 years; The second most efficient system; The second lowest energy consumption; Responsible for the second lowest CO2 emissions, and Zero ODP. CONCLUSION Experimental and numerical investigations of chiller and hot water supply have been proceeded to assess energy and temperature performance of hotel cooling and heating systems. The experimental directly observed the chiller systems when in operation, measured performance parameters, processed data and simulated energy performance, established feasibility analyses and provided recommendations for energy saving potential and economic viability of chiller application. Feasibility analyses on the proposed cooling and heating system alternatives show that for energy conservation purposes, the most feasible cooling and heating system applied for the case study hotel is the Alternative-2 which comprises; 650 TR centrifugal chiller R-123 to be integrated with two units heat pump of @364 kW heating capacity. The system consumes the lowest energy and responsible for the lowest CO2 emission to environment. The system, however, uses refrigerant R-123 which has ODP of 0.02. The phase out of refrigerant R-123 for Indonesia will be in 2040. This energy efficient

chiller will still be cost-effective for 19 years operation, if the system is installed in 2021. This alternative has high energy performance and low environmental impact. For lifetime application (more than 15 years) the alternative is economically more viable than other alternatives. The seconds best energy and environmental performance alternative is system of Alternative-1 (650 TR centrifugal chiller R-134a and two units heat pump of @364 kW) is also feasible for the hotel. Its energy performance and economic viability is slightly below the Alternative-2. This alternative consumes 2,493 MWh electricity per year and responsible for 1,536 ton-CO_2/year. Its environmental impact in term of CO_2 emissions is slightly higher than alternative-2 but it has zero ODP.
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