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Journal of Physics: Conference Series PAPER • OPEN ACCESS Minimizing temperature instability of heat recovery hot water system utilizing optimized thermal energy storage Minimizing temperature instability of heat recovery hot water system utilizing optimized thermal energy storage I N Suamir*, I B P Sukadana and M E Arsana Mechanical Engineering Department, Bali State Polytechnic, Bali, 80364, Indonesia *Email: nyomansuamir@pnb.ac.id Abstract. One energy-saving technology that starts gaining attractive for hotel industry application in Indonesia is the utilization of waste heat of a central air conditioning system to heat water for domestic hot water supply system. Implementing the technology for such application at a hotel was found that hot water capacity generated from the heat recovery system could satisfy domestic hot water demand of the hotel. The gas boilers installed in order to back up the system have never been used. The hot water supply, however, was found to be instable with hot water supply temperature fluctuated ranging from 45 °C to 62 °C. The temperature fluctuations reaches 17 °C, which is considered instable and can reduce hot water usage comfort level. This research is aimed to optimize the thermal energy storage in order to minimize the temperature instability of heat recovery hot water supply system. The research is a case study approach based on cooling and hot water demands of a hotel in Jakarta-Indonesia that has applied water cooled chillers with heat recovery systems. The hotel operation with 329 guest rooms and 8 function rooms showed that hot water production in the heat recovery system completed with 5 m3 thermal energy storage (TES) could not hold the hot water supply temperature constantly. The variations of the cooling demand and hot water demands day by day were identified. It was found that there was significant mismatched of available time (hours) between cooling demand which is directly correlated to the hot water production from the heat recovery system and hot water usage. The available TES system could not store heat rejected from the condenser of the chiller during cooling demand peak time between 14.00 and 18.00 hours. The extra heat from the heat recovery system consequently increases the temperature of hot water up to 62 °C. It is about 12 K above 50 °C the requirement hot water temperature of the hotel. In contrast, the TES could not deliver proper temperature of hot water during peak hot water demand and on that time between 06.00 and 10.00 hours, the hotel also experiences a low cooling demand. Subsequently, the temperature of hot water supplied drops down as low as 45 °C. The study was found that optimization on the TES can significantly minimize temperature variation of the hot water supplied to the hotel appliances. A TES of 30 m3 storage capacity is considered the optimum capacity which can reduce the temperature fluctuation from 17 K down to 3 K. The study also found that maintaining the storage temperature relatively lower than the condenser temperature could increase hot water production of the heat recovery system. 1. Introduction Energy consumption for the commercial sector such as office buildings, hospitals, hotels, supermarkets including airports in Indonesia was about 3.7% of total national energy use [1]. The consumption growth of the sector was the second highest with average growth of 4.58% per year [2]. While energy saving potential of the sector was estimated ranging from 10% to 30% with energy saving target of the sector in 2025 was estimated to be 15% [3]. Especially for hotel buildings, the growth of the buildings in past three years reached an average of 11.2% [4]. In addition of that the hotels are one of the most energy intensive building types because of their multi-services and 24 hours operation per day [5]. Their services-facilities such as air conditioning (AC) and hot water systems consume significant energy which can reach 60% - 70% of the total energy use [6]. This would subsequently increase further the energy consumption of the commercial sector. Energy consumption intensity of hotels in Indonesia is fairly high. Earlier research of four-star hotel in Jakarta showed that the energy intensity was as high as 495 kWh/m2/year. Most of the energy source is from electricity with 91.7% energy share and LPG (liquid petroleum gas) of 7.8% mainly for hot water production. The hotel also consumed diesel fuel for local electricity generation of about 0.5% [7]. This can be compared with those of other countries such as UK, New Zealand, Taiwan, Hong Kong, China and Turkey of respectively 368, 159, 295, 342, 165 and 389 kWh/m2/year [8-11]. In Singapore, most of hotel buildings also used electricity as the main energy source. The percentage could be 91% for hotels that only used electricity and gas. Hotels that also consume diesel fuel the percentage of electricity drops to 77% [12,13]. The energy use of the hotels directly contributes to the operating cost. Generally the energy cost accounts for ranging from 4% up to 10% of total operating costs or even higher for luxury hotels which ranging between 20% and 25% for luxury hotels [6,14] In Indonesia, the hotel industry is experiencing rapid growth. Based on reference [4] the number of star hotels reached 1,778 units with 171,432 rooms. The average occupancy rate reached 53%. Thus saving energy consumption would contribute significantly to the reduction of greenhouse gas emissions into the environment. In addition, energy savings would provide benefit for the hotel industry: reduce operating costs and increase profitability. While the benefits of energy savings country-wide would be able to reduce energy supply from the grid and reduce environmental impact. One good conservation technology in air conditioning and a hot water supply systems that was implemented in the hotel building in Indonesia is integration of central air conditioning system with hot water supply system through a heat recovery system. This integrated system, besides providing cooling, can also simultaneously supply heat for heating water which is used for hot water supply system in the hotel by utilizing part of the waste heat of condenser. This integrated system can reduce about 6.6% of energy consumption [7,15]. Drawback of the integrated system is that the production capacity of the hot water is highly dependent on the cooling load of the central air conditioning system. The hot water production reduces when the air conditioning system load factor decreases. Investigation at a hotel in Jakarta that has used conservation technology with an integrated system showed that hot water supply temperature fluctuated in the range from 45 °C up to 62 °C, while the temperature of the hot water required by the hotel management is 50 °C. Fluctuations in hot water supply temperature reaches 17 °C. This is considered unstable and can reduce hot water usage comfort level. Wide temperature variation was caused by the production of hot water from the heat recovery system was imbalanced with the hotel hot water demand especially during the hours of peak usage of hot water. In comparison, when using hot water supply system from gas boiler the temperature of the hot water supply is very stable at 50 °C – 52 °C. One way to minimize fluctuation of hot water supply due to imbalance between hot water production and demand is by implementation of thermal energy storage (TES). For applications in hotel buildings, TES is usually required for short periods. Therefore TES solution is simple by using a hot water storage tank. This type of TES system is well-known, reliable and very superior in terms of system simplicity and installation costs [16-19]. The efficiency of the TES system for hot water applications is in the 50% - 90% range and can be improved by the use of appropriate tank wall materials [20] and by applying the painting on the inner wall as inner lining [21]. This study examined variation of the hot water production from the heat recovery system and hot water demand as well as simulating and investigating the capacity requirements of the hot water storage tank that can minimize temperature fluctuations when there is an imbalance between hot water production and hot water demand. 2. Methods Figure 1 shows the schematic of energy system for cooling and hot water supply of hotel buildings that has been investigated numerically and experimentally in this research. The energy system is integration between air conditioning and hot water heat recovery systems. The air conditioning system is a centralized water cooled chiller while the hot water system is a heat recovery system completed with thermal energy storage tank (TES) without additional hot water supply as presented in Figure 1. TES tank-2 Pump Main water supply Cold and hot water taps Hot water supply system Heat Cooling TES tank-1 recovery tower HX Pump Pump Condenser Liquid receiver Compressor Cooling load Evaporator Centralized AC with HR system Figure 1. The concept of the hot water supply system with heat recovery central air conditioning system and hot water storage tank START Ambient parameters; refrigerant use; Hot Water (HW) demand; Cooling demand (Qevap) Degree of superheat, degree of sub-cooling, compressor efficiency, evaporator and condenser approach temperatures Cooling water (CW) parameters: LCWT, PCW; Chilled water (ChW) parameters: LChWT, PChW Hot water (HW) and Heat recovery (HR) heat exchanger (HE) parameters: EHWT, PHW and HRHE effectiveness Predict: Flowrate of HW, CW and ChW Calculate: power consumption, ECWT, EChWT, LHWT, ΔTCW, ΔTChW, refrigerant parameters: pressures, temperatures, enthalpy and mass flow rate Guess other value of flow rate No ΔTCW = 5 K ΔTChW = 5 K LHWT = 50oC Yes E = entering, L = leaving, ΔT = temperature difference, COP = coefficient of performance, TR = ton of refrigeration Determine: power consumption, CW flowrate, ChW flowrate, HW flowrate refrigerant flowrate, HR heat, condenser heat, COP, kW/TR END Figure 2. Flowchart of numerical models in EES for the water cooled chiller with hot water heat recovery system Numerical approach applied in this research was using EES (Engineering Equations Solver). The model required input parameter which included environmental conditions, temperature and pressure of the refrigeration system as well as temperature (T) and pressure (P) of the hot water system. The output parameter covered energy consumption and optimum size of the thermal energy storage. The equations of energy balance applied for each component in the model refers to the sources that have been published. Flowchart of the EES-based numerical models are presented in Figure 2. 3. Results and Discussion Surveys on the technical and operational specifications of the data on the system Chiller equipped with a heat recovery system were carried out at the Mercure Convention Center (MCC) which is located at Jl. Pantai Indah, Taman Impian Jaya Ancol, North Jakarta 14430. Data technical specifications and operational surveyed include variations of usage of hot water, hot water supply temperature fluctuation, the occupancy rate of hotels and variations of the cooling load factor of central air conditioning system. Hotel surveyed had 3 each chiller unit is Hitachi water-cooled water chiller-type screw-R410A series Heat Recovery (HR) with a cooling capacity of 265 TR (Tons of Refrigeration) and heat recovery capacity of 132 kW. Instrumentation used was an integral part of the monitoring system in particular chiller air conditioning system for the operational parameters of the air conditioning system includes cooling water temperature, chilled water temperature and the working pressure system. The power consumption of the system Chiller is an additional instrument which is specifically fitted for monitoring the energy consumption of the system. The system is not equipped with a cooling water flow gauges and chilled water. These parameters were measured with a portable instrument concealment time of the survey. The instruments are complementary to the chiller system and additional instruments. a). Heat recovered through the HR system 210 Heat Recovered (kW) 180 150 120 90 60 30 0 0 2 4 6 8 10 12 14 16 18 20 22 24 Hours b). Cooling capacity of the chiller 1200 Cooling Capacity (kW) 1000 800 600 400 200 0 0 2 4 6 8 10 12 14 16 18 20 22 24 Hours Figure 3. Hourly variation of heat recovered through the HR system and cooling capacity of the chiller The temperature of the hot water from the HR system that was distributed to facilities fluctuates at the range of 45 °C up to 62 °C. The hot water temperature changes along with the amount of heat recovered in the HR system and cooling capacity of the chiller. The hourly variation of parameters, the amount of heat recovered and cooling capacity of the chiller, in one day can be seen in Figure 3. In Figure 4a is shown that chiller system with cooling load fluctuations. From this figure it can be seen that the air-conditioning system load will increase significantly starting at 8 a.m. and reached the highest peak from about 1 p.m. to 7 p.m. Then start to decline quite sharply from 7 p.m. to the next morning at 5 a.m. This causes the temperature of hot water to be extremely high which occurs during peak hours of cooling demand (high cooling load factor) and relatively low when the cooling load factor decreases (Figure 4b). In order to prevent temperature fluctuations of the hot water produced in the HR system, this study has investigated and optimized thermal storage technology applied to store the heat energy recovered during peak load of the air conditioning system and then the stored heat can be used again when the heat recovered in the HR system is small which typically occurs when the cooling load factor of the chiller is low. a). Cooling load factor of the chiller b). Temperature of the hot water (HW) Cooling load Factor (%) 120 100 80 70 80 60 40 20 HW Temperature (°C) 60 50 40 30 20 10 0 0 0 2 4 6 8 10 12 14 16 18 20 22 24 Hours 0 2 4 6 8 10 12 14 16 18 20 22 24 Hours Figure 4. Hourly variation of cooling load factor of the chiller and hot water temperature produced from the heat recovery (HR) system Energy performance of chiller surveyed in MCC Ancol Jakarta at different load factor is presented in Figure 5. It can be seen that in general the specific energy consumption of the chiller is still relatively close to the manufacturer's specifications in the range of 0.53 to 0.62 kW/TR when the chiller is operated at load factor of 45 - 83% but it relatively goes up to above 0.65 kW/TR when operated at a load factor over 90%. The specific energy consumption shown in Figure 5 was calculated by taking into account the production of hot water generated in the heat recovery system. Specific energy consumption (kW/TR) 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0 Manufacturer specification Chiller-1 Chiller-2 Chiller-3 0 10 20 30 40 50 60 70 80 90 100 110 120 Load Factor (%) Figure 5. Variation of chiller system energy performance at different load factor The numerical analysis of hot water production and daily hot water demand is presented in Figure 6. From the figure it can be seen that the production of hot water (HW) from the heat recovery system is very volatile following the workload of the chiller system. Optimum HW production can be achieved during the day from 1 p.m. to 8 p.m. with the highest production of about 4.2 m3/h obtained at 6 p.m. While the lowest production is reached in the morning. Figure 6 also provides hot water demand with peak demand occurring in the morning from 6 a.m. to 10 a.m. Hot water demand also relatively increase in the evening around at 7 p.m. until 10 p.m. Figure 6 also clearly shows that there is an imbalance between peak hot water demand and optimum hot water production from heat recovery system. 5.0 5.0 HW Generated (m3/hr) 4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 HW generated (m3/hr) HW Demand (m3/hr) 4.5 4.0

3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0 0 2 4 6 8 10 12 14 16 18 20 22 24 Hours Figure 6. Variation of HW generated from HR system and HW demand HW Demand (m3/hr) As the result, the fluctuation of the hot water temperature of the hotel to be relatively very high with 17 K temperature difference. This will lead to discomfort in the use of hot water especially for bathing. In order to decrease the fluctuation of hot water supply temperature from the heat recovery system, the HW storage tank need to be optimized. The results of the optimization done by using EES software can be seen in Figure 7. The application of hot water tanks with an optimized capacity is able to overcome the imbalance between the hot water production and demand. If hot water production of the HR chiller system is higher than the demand then some heat must be stored in the water storage tank, and this process is called charging. In contrast, hot water from the storage tank would be discharged when the hot water production is below demand. This process is called discharging. For those purposes, the hot water storage tank should be designed to enable to store and supply hot water maintaining stability between supply and demand as shown in Figure 8b. 56 54 HW Temperature (°C) 52 50 48 46 44 42 40 Discharge at 7 a.m. Discharge at 8 a.m. Diacharge at 9 a.m. Charge at 11 a.m. 38 Charge at 12 a.m. Charge at 2 p.m. 36 2 6 10 14 18 22 26 30 34 38 42 46 50 HW Tank Capacity (m3) Figure 7. Variation of hot water temperature after charging and discharging processes at different capacity of the storage tank In Figure 7 we can also see the simulation results for the charging and discharging process of the hot water tank. Hot water temperatures for hotels are generally kept at 50 °C. To ensure the comfortable use of hot water, the supply fluctuations must be within the range of 50 °C ± 2 °C. For the profile of hot water demand and production capacity as shown in Figure 6, the optimum tank size obtained from the simulation and validated with data obtained directly from the installed system is 30 - 34 m3 (shown in Figure 7 and 8a). The optimum tank capacity obtained is much closed to daily hot water demand of the hotel in the range of 36 m3 per day. The optimization simulation of hot water tank was done by using entering cold water temperature of 26 °C. a). HW supply temperature difference ΔT HW supply in 24 hours (K) 18 16 14 12 10 8 6 4 2 0 20 2 6 10 14 18 22 26 30 34 38 42 46 50 HW Tank Capacity (m3) b). HW supply temperature after optimization 80 70 HW Temperature (°C) 60 50 40 30 ΔT = 3.8 K 20 Tmax = 53.3 °C 10 Tmin = 49.5 °C 0 0 2 4 6 8 10 12 14 16 18 20 22 24 Hours Figure 8. HW temperature difference at various storage tank capacity and variation of HW temperature after optimization 4. Conclusions Experimental and numerical investigations have been conducted on optimization of heat recovery hot water production which would be implementing for application at a hotel with a hot water storage tank 5 m3 indicated that the temperature of the hot water supply fluctuated with supply temperatures up to 45 °C to 62 °C. Fluctuations in hot water supply temperature reaches 17 K is considered unstable and can reduce hot water usage comfort level. The hot water production was imbalanced with the demand, especially during the hours of peak usage of hot water. Examination on the research covered the variation of the production capacity of the hot water from heat recovery system and hot water demand fluctuations in the hotel as well as simulation of the capacity requirements of hot water storage tank that could handle temperature fluctuations when there was imbalance between production and hot water demand. The optimized capacity of hot water storage tank was found to be 30 - 34 m3. This storage capacity was also found to be matched with daily hot water demand of the hotel and could provide optimum hot water supply relatively constant with controllable temperature supply. 5. Acknowledgments The authors acknowledge the financial support received from the Higher Education Directorate General of the Ministry of Research, Technology and Higher Education of the Republic of Indonesia. 6. References [1] Respati J 2016 Prospects of Energy Efficiency and Conservation in Indonesia (Indonesian Energy

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