# An Assessment of Feasibility of Energy Saving Measures Applied for a Hospital

Cheng-Shu Kuo[1], Chen-Pu Wang[2], Fu-Jen Wang[2], Pei-Yu Yu[1] and Hung-Wen Lin[1]
[1]*Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, Hisnchu, Taiwan*
[2]*Department of Refrigeration, Air Conditioning and Energy Engineering,*
*National Chin-Yi University of Technology, Taichung, Taiwan*

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Abstract: The objective of this study, including field investigations and simulations, is to evaluate the feasibility of retrofit for energy performance of a hospital in the midst of Taiwan. This hospital, twelve stories and two floors of basements, has 37490 m$^2$ of gross floor area, consuming around 8500000 kWh annually. The current internal systems of this hospital present relevant signs of degradation and obsolescence. Concerning this matter, the retrofit plan of internal systems for this hospital is conducted to improve energy performance. Based on ASHRAE procedures for commercial building energy audits (PCBEA), field study and energy audits were conducted to collect information of building geometry, building materials, space types, density and activities of people, capacity of HVAC system, loads and operating schedules of lighting and internal equipment. Using this information, a hospital energy model with the current internal system arrangements is established using EnergyPlus software, calibrated by field information of this building as a baseline. The energy saving potentials of several energy saving measures applied such as high-performance chillers and lighting devices, window glass with tinted film and energy management resulting from EnergyPlus simulations have been examined with reference to the cooling energy demand. The retrofit feasibility has also been evaluated in terms of annual savings and pay-back period of the investment. Those analyses could be beneficial to establish a feasible retrofit plan for energy saving of this building.



## 1 INTRODUCTION

Taiwan is a small island with rare indigenous energy, 97% of energy imported from overseas. Recently, scales of building in Taiwan such as office buildings, department stores, hospitals and hotels were increasing, consuming large amount of electricity. From the current situation and future trend of electricity demands and percent reserve margin of capacity of Taiwan, shown in the Figure 1, it can be found that electricity demands of Taiwan increase with years while percent reserve margin of capacity decreases with years. Therefore, how to reduce the electricity consumption and improve energy efficiency has become a key issue for energy management of Taiwan. According to investigations (Bureau of Energy of Taiwan, 2015) from Bureau of Energy of Taiwan, there are 145 hospital buildings with contract capacity above 800 kW, consuming 2.1 billion kWh per year, about 14.9 % of electricity consumption of non-productive industries in Taiwan. In addition, average electricity consumption per unit area of medical centres and regional hospitals are 245 kWh/m$^2$yr and 205 kWh/m$^2$yr, respectively, about 1.47 to 1.75 times of the one of office buildings. Hospitals provide patients with 24 hours of lighting, air conditioning and healthcare facilities to meet the requirements of medical care, thus consuming large amount of electricity. The Taiwan government has set the energy saving target that Mega-Watt energy users would have 1% of energy reduction per year in the following 5 years (Bureau of Energy of Taiwan, 2015). Concerning this matter, hospital buildings would have to implement energy-saving measures in order to reduce electricity consumption and to reach the Taiwan government's energy saving target.

Energy simulation is a useful method to evaluate influence factors on building energy performance such as building materials, power densities of lighting and internal electrical equipment, air conditioning system, and operation schedules etc., especially useful for the early designing or retrofit planning stage of such large scale hospital buildings.



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Energy simulations have been applied to analyze energy performance of hospital buildings in several previous works. The building energy simulations were employed to evaluate the energy-saving efficiency of HVAC system by studying two green hospital buildings (Chen and Kan, 2014), to examine thermal performance of hospital buildings with various geometries (Shchuchenko et al, 2013), to calculate heating and cooling loads of the hospital (Saipi et al, 2014), to assess the feasibility of 50% energy savings for large hospitals in various climate zones of USA (Bonnema et al. 2010), and to evaluate impacts of both envelope renovation and HVAC system selection for a hospital building (Ascione et al, 2016) etc. It is indicated that the building energy software can help to obtain a better understanding of energy consumption throughout the whole building. Therefore, EnergyPlus building energy simulation software developed by Department of Energy of USA was used in this report to calculate energy consumptions of energy saving measures applied on this hospital to evaluate the feasibility of a retrofit plan for energy saving of this building, located in the midst of Taiwan.

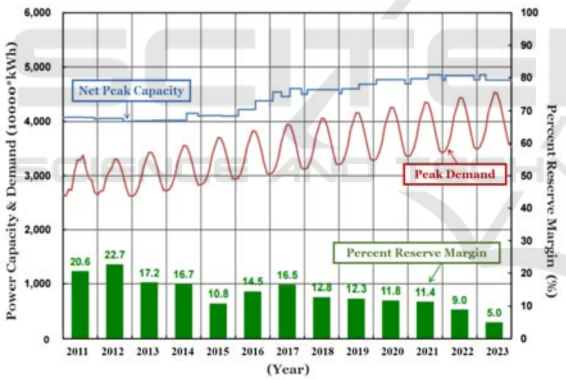


Figure 1: Trend of net peak capacity, peak demand and percent reserve margin of Taiwan. (Taipower Company, 2011).

This paper is organized as follows. Section 2 is to obtain completed information of the hospital building employing ASHRAE procedures for commercial building energy audits (PCBEA) (ASHRAE, 2011) for information of building geometry, building materials, space types, density and activities of people, capacity of HVAC system, loads and operating schedules of lighting and internal equipment. Based on collected information, an energy model for this hospital was established using EnergyPlus software, while this energy model was calibrated by actual monthly electricity as a retrofit baseline. Section 3 describes the evaluations of applied energy saving measures. It will compare annual energy saving and pay-back period of the investment among the existing baseline and energy saving measures to evaluate retrofit feasibility. Finally, Section 4 presents our conclusions

# 2 ENERGY MODEL OF THIS HOSPTIAL BUILDING

## 2.1 Specification of Building

This hospital building is located in the midst of Taiwan, built in twelve floors above ground and two floors underground, with base area 64 meter by 58.6 meter. The front of this hospital building faces northwest. The first floor is the lobby and emergency rooms. From the 5th floor to the 11th floor, all spaces are wards except some spaces in 10th floor are used for negative pressure isolation rooms. The 12th floor contains an auditorium, meeting rooms and negative pressure isolation rooms. The detailed information of area and space types of each floor of this building is shown in Table 1.

Table 1: Specification of building.

| Floor | Floor area (m$^2$) | Space property |
|---|---|---|
| B1 | 3749 | Radiology department; Morgue; Parking lot |
| B2 | 3749 | Restaurant; Pharmacy; Medical records department |
| 1F | 3749 | Lobby; Emergency room |
| 2F | 3749 | Outpatient Clinic |
| 3F | 3749 | Intensive care unit; Operating room |
| 4F | 3749 | Air conditioning machine room |
| 5F | 1874.5 | Ward |
| 6F | 1874.5 | Ward |
| 7F | 1874.5 | Ward |
| 8F | 1874.5 | Ward |
| 9F | 1874.5 | Ward |
| 10F | 1874.5 | Ward; Negative pressure isolation room |
| 11F | 1874.5 | Ward |
| 12F | 1874.5 | Negative pressure isolation room; Auditorium; Meeting room |

## 2.2 Construction of the Building

According to the architectural drawing of this building, the construction, appearance and interior partition of the building are established. The roof of this building is reinforced concrete with regular insulation (overall heat transfer coefficient U = 0.99 W/m$^2$K). Exterior wall is 15 cm reinforced concrete with tiles (overall heat transfer coefficient U = 3.49 W/m$^2$K). Window glass is 8 mm brown colour glass (overall heat transfer coefficient U = 6.07 W/m$^2$K, solar heat gain coefficient SHGC = 0.82). The building model is built up following the geometric dimensions of the building in the architectural drawing. The complicated geometric dimensions of the building are simplified without influencing the simulations. The actual appearance and 3D model of the building are shown in Figure 2 and 3. The interior partitions of each floor of this building are independently established according to the architectural drawing. Some spaces without air conditioning or with the same property are simply combined into a space to reduce the complexity of building model.

Figure 2: Actual appearance of the hospital.

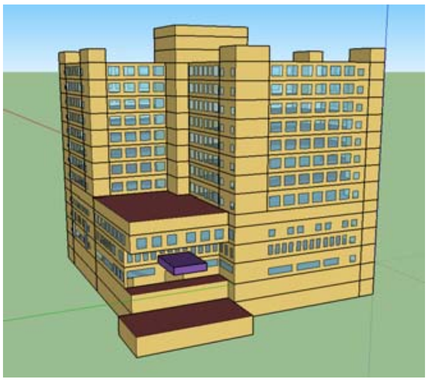

Figure 3: 3D model of the hospital.

## 2.3 Interior Load Parameters

According to field investigation, the average people, lighting density and internal electrical equipment density of each floor of this hospital are shown in the Table 2.

Table 2: Average interior loads of building.

| floor | People number | Lighting density (W/m$^2$) | Internal electrical equipment density(W/m$^2$) |
|---|---|---|---|
| B2 | 100 | 15 | 15 |
| B1 | 200 | 30 | 15 |
| 1F | 300 | 25 | 15 |
| 2F | 160 | 25 | 20 |
| 3F | 160 | 20 | 10 |
| 4F | 5 | 5 | 10 |
| 5F | 160 | 25 | 10 |
| 6F | 160 | 25 | 10 |
| 7F | 160 | 25 | 10 |
| 8F | 160 | 25 | 10 |
| 9F | 160 | 25 | 10 |
| 10F | 160 | 25 | 15 |
| 11F | 160 | 25 | 10 |
| 12F | 100 | 15 | 10 |

## 2.4 Schedule

During simulations, schedules of people activity, lighting, internal electrical equipment and air conditioning system need to be input to represent time variation of people number and power density of related equipment. The effect of time variation is expressed using the number of fraction of peak. When full load is done, fraction of peak is set to be 1. On the other hand, fraction of peak is 0 when the load is off. The value of fraction of peak is between 0 and 1 when it is partial load. In this report, schedules were derived based on engineering judgment and field investigation. Figure 4 shows the time variation of people number in the hospital building. Y-axis represents the ratio of people number of the current time to the peak people number. Figure 5, 6, and 7 plot the lighting, internal electrical equipment, and air conditioning system schedules in the hospital building. For special spaces in the hospital such as emergency rooms and intensive care unit, the fraction of peak of schedules remains one for 24 hours throughout the whole year.

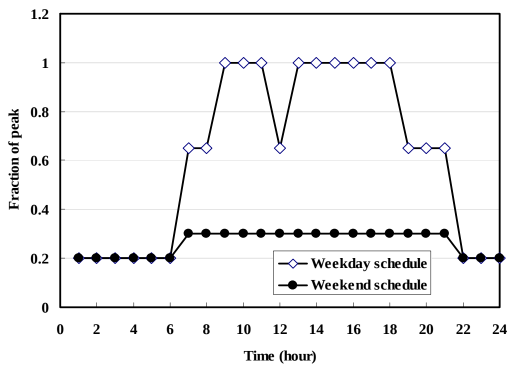


Figure 4: Occupancy schedule.

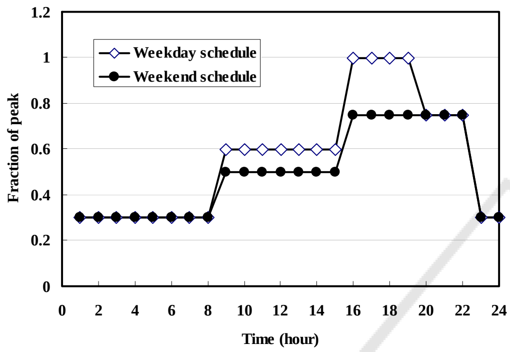


Figure 5: Lighting schedule.

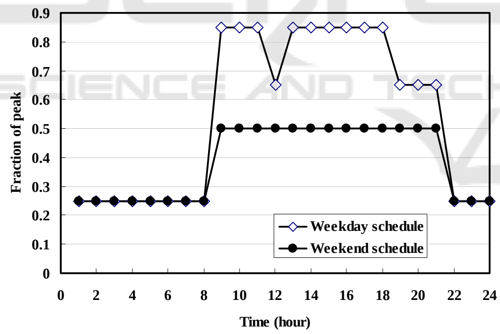


Figure 6: Internal electrical equipment schedule.

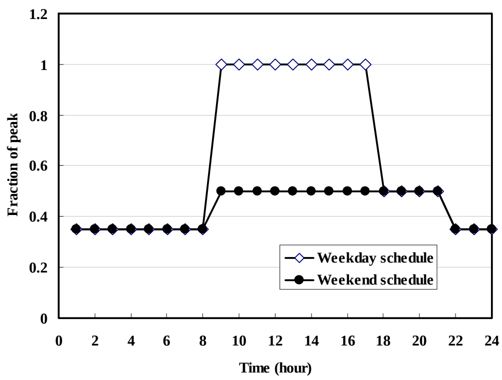


Figure 7: Air conditioning system schedule.

## 2.5 Air Conditioning System

This air conditioning system of this hospital contains two 540 RT chillers in a parallel configuration and a 250 RT chiller, with rated COP of 5.0, 5.0 and 4.0, respectively. These chillers work using 5 chilled water pumps and 7 regional chilled water pumps to cool the rooms inside the building, illustrated in Figure 8. Also, these chillers employ 5 cooling water pumps and 5 cooling towers to release heat to the environment, shown in Figure 9. Specifications of chillers are indicated in Table 3. The chiller of 250 RT works 24 hours whole year to meet the requirements of cooling loads of special spaces such as emergency rooms and intensive care unit. Two 540 RT chillers satisfy the cooling demands for all regular rooms, operating with the air conditioning system schedule indicated in Figure 7. The efficiency of fans used in air conditioning system is 0.6. The room temperature of regular space is set at 25 ℃.

Table 3: Specifications of chillers.

| No. | CH1 | CH2 | CH3 |
|---|---|---|---|
| Capacity (RT) | 540 | 540 | 250 |
| Power consumption (kW) | 384 | 384 | 198 |
| Inlet/outlet chilled water temp. (℃) | 12/7 | 12/7 | 12/7 |
| Inlet/outlet cooling water temp. (℃) | 32/37 | 32/37 | 32/37 |

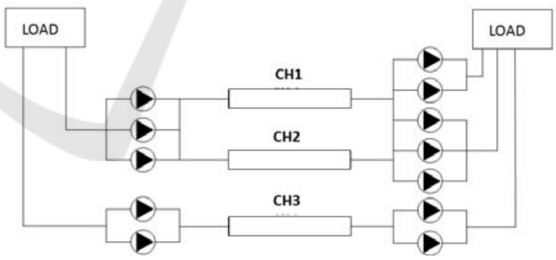


Figure 8: Chillers, chilled water pumps and regional chilled water pumps.

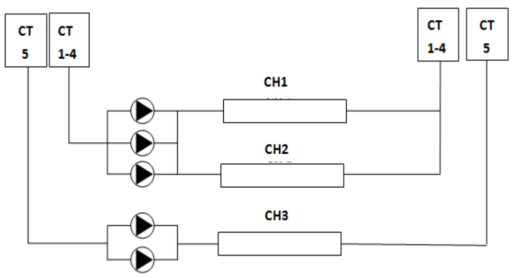


Figure 9: Chillers, cooling water pumps and cooling towers.

### 2.6 Baseline Model

A building model with above settings including construction and materials, internal loads, schedules and air conditioning system is simulated using EnergyPlus software. The simulation result of electricity consumption of this building is compared with measured electricity consumption in 2015, listed in Table 4. The deviation of total annual electricity consumption between simulation and actual measured data is about 3.64% and the trends of monthly electricity usages of both are similar and closed. The allowable difference between predicted and measured data is that the annual simulated energy usage should be within 10% of metered data, while a difference of less than 25% is acceptable on a seasonal basis (Rahman et al, 2010). From the simulation result, it is indicated that this building model can be the baseline for retrofit evaluations in terms of total annual electricity consumption.

Table 4: Comparison between actual and simulation data.

| Month | Actual (kWh) | Simulation (kWh) | Deviation (%) |
|---|---|---|---|
| 1 | 595,832 | 638,165 | 7.10 |
| 2 | 528,308 | 566,942 | 7.31 |
| 3 | 621,872 | 669,196 | 7.61 |
| 4 | 620,990 | 653,532 | 5.24 |
| 5 | 707,569 | 739,281 | 4.48 |
| 6 | 720,664 | 723,314 | 0.37 |
| 7 | 855,248 | 881,724 | 3.10 |
| 8 | 827,073 | 799,616 | -3.32 |
| 9 | 801,520 | 752,193 | -6.15 |
| 10 | 657,216 | 715,404 | 8.85 |
| 11 | 612,632 | 668,029 | 9.04 |
| 12 | 590,675 | 628,319 | 6.37 |
| Total | 8,139,599 | 8,435,715 | 3.64 |

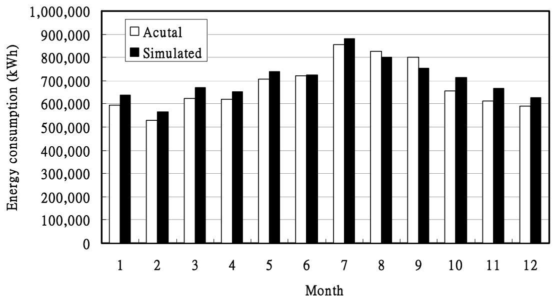


Figure 10: Simulation result and comparison with measured data.

## 3 EVALUATION OF ENERGY SAVING MEASURES

Based on baseline energy model of this hospital building, calculations of energy saving and pay-back period of investment of energy saving measures applied on air conditioning system, ventilation system, lighting system, internal electrical equipment, building materials and energy management are conducted as follows.

Baseline: The EnergyPlus building model with current internal system, which has been calibrated with the monthly electricity consumptions of the hospital building in 2015.

Measure 1: The original chiller of 250 RT with COP = 4.0 is replaced by a new chiller of 250 RT with COP = 5.0. After this improvement, total annual energy consumption is 8,115,158 kWh, saving 3.8% of electricity about reduction of 31,022 USD (US Dollar). If cost of this improvement is 80,646 USD, the return on investment (ROI) will be 2.6 years.

Measure 2: This measure is to increase outlet chilled water temperature of chillers from 7ºC to 8ºC. According to the required working condition of air handling units, the apparatus dew point is 13.5ºC. Generally, the temperature difference between inlet and outlet chilled water of the chiller is 5ºC. Therefore, when outlet chilled water temperature of chillers is from 7ºC to 8ºC, the apparatus dew point can reach to 13.5ºC. It means that this change will not influence the working condition of cooling coils of air handling units. This measure can be implemented easily by changing the temperature setting value on the control panel of the chiller. After this setting, total annual energy consumption is 8,345,617 kWh, saving 2.1% of electricity about reduction of 17,438 USD. Since cost of this improvement is 0 USD, the return on investment (ROI) is 0 year.

Measure 3: Decreasing inlet cooling water temperature of chillers from 32ºC to 31ºC is applied to save energy. Based on the consideration of capacity of current cooling tower, properties of chiller and outdoor wet-bulb temperature without significant deviations from the standard operation conditions suggested by manufacturers, slightly decreasing 1ºC on inlet cooling water temperature of chillers is proposed to observe the variation of total energy consumption. This measure can be carried out by simply changing the setting values of inlet cooling water temperature on the control panel of chillers. After this change, total annual energy consumption is 8,365,667 kWh, saving 1.1% of electricity about reduction of 8,720 USD. Since cost of this improvement is 0 USD, the return on investment (ROI) is 0 year.

Measure 4: Employing the tinted window film on window glass of the building as thermal insulation, the solar heat gain coefficient (SHGC) of window glass with tinted film is reduced from 0.81 to 0.51. After this improvement, total annual energy consumption is 8,365,667 kWh, saving 0.8% of electricity about reduction of 6,780 USD. Since cost of this improvement is 92,746 USD (total glass area is 2395.94 $m^2$ and cost is 38.7 USD/$m^2$), the return on investment (ROI) is 13.7 years.

Measure 5: The original lighting systems for existing building using T-8 fluorescent lamps are replaced by T-5 fluorescent lamps. Therefore, by this energy saving measure, the average lighting density in all spaces will be 0.85 times of the original lighting density. After this improvement, total annual energy consumption is 8,112,018 kWh, saving 3.8% of electricity about reduction of 31,326 USD. Since cost of this improvement is 222,161 USD, the return on investment (ROI) is 7.1 years.

Measure 6: High-performance appliances are applied to reduce energy consumption of internal electrical equipment. By this measure, energy consumption of internal electrical equipment is estimated to be 0.94 times of original one. If this improvement is conducted, total annual energy consumption will be 8,300,822 kWh, saving 1.6 % of electricity about reduction of 13,054 USD. Since cost of this improvement is 70,000 USD, the return on investment (ROI) is 5.36 years.

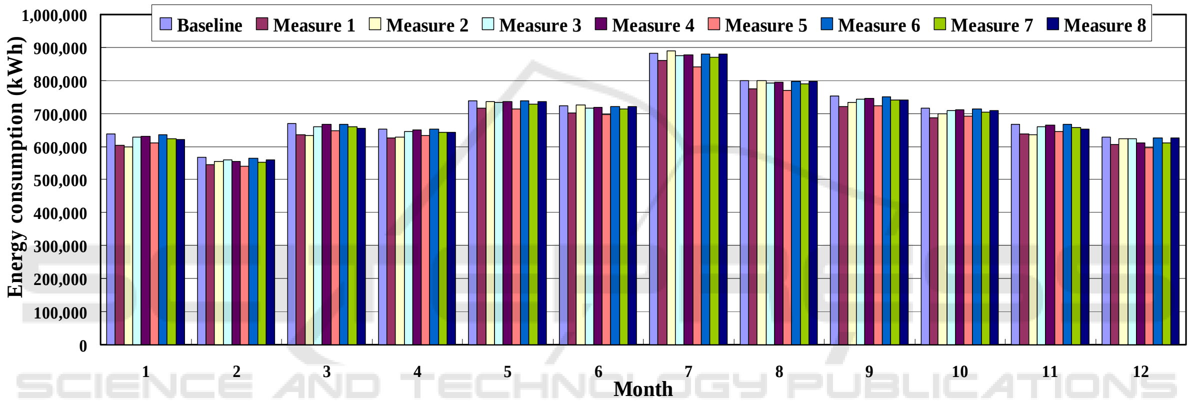


Figure 11: Simulation results of energy saving measures and comparison with baseline data.

Table 5: Results of energy saving measures.

| Month | Baseline (MWh) | Measure 1(MWh) | Measure 2(MWh) | Measure 3(MWh) | Measure 4(MWh) | Measure 5(MWh) | Measure 6(MWh) | Measure 7(MWh) | Measure 8(MWh) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 638.17 | 605.07 | 598.83 | 628.38 | 630.55 | 611.38 | 636.33 | 624.65 | 621.67 |
| 2 | 566.94 | 544.17 | 554.79 | 558.89 | 554.14 | 540.88 | 565.18 | 553.55 | 560.57 |
| 3 | 669.20 | 636.65 | 632.63 | 660.16 | 667.35 | 647.42 | 667.89 | 659.46 | 654.75 |
| 4 | 653.53 | 624.92 | 627.20 | 646.13 | 651.03 | 633.43 | 652.22 | 643.97 | 643.18 |
| 5 | 739.28 | 716.11 | 736.84 | 732.91 | 736.11 | 713.28 | 737.91 | 728.77 | 736.13 |
| 6 | 723.31 | 701.41 | 725.10 | 716.68 | 719.20 | 697.67 | 721.97 | 713.00 | 721.03 |
| 7 | 881.72 | 859.65 | 889.26 | 874.86 | 877.68 | 840.54 | 880.37 | 871.29 | 879.43 |
| 8 | 799.62 | 775.21 | 800.33 | 792.46 | 794.21 | 769.42 | 798.22 | 788.71 | 796.02 |
| 9 | 752.19 | 722.16 | 733.26 | 743.80 | 745.46 | 724.79 | 750.84 | 741.66 | 740.47 |
| 10 | 715.40 | 686.17 | 699.36 | 709.06 | 711.67 | 691.73 | 714.05 | 705.13 | 709.56 |
| 11 | 668.03 | 637.07 | 635.45 | 659.73 | 666.20 | 645.88 | 666.76 | 658.57 | 653.79 |
| 12 | 628.32 | 606.59 | 622.48 | 622.55 | 612.08 | 595.60 | 626.08 | 612.08 | 625.89 |
| Total | 8435.72 | 8115.16 | 8255.52 | 8345.62 | 8365.67 | 8112.02 | 8417.82 | 8300.82 | 8342.48 |
| Energy saving (%) | -- | 3.8 | 2.1 | 1.1 | 0.8 | 3.8 | 1.6 | 0.2 | 1.11 |
| ROI (year) | -- | 2.6 | 0 | 0 | 13.7 | 7.1 | 5.36 | 37.3 | 0 |

Measure 7: This measure is to improve the fan efficiency in the ventilation systems from 0.6 to 0.7. If this improvement is conducted, total annual energy consumption will be 8,417,819 kWh, saving 0.2% of electricity about reduction of 1,732 USD. Since cost of this improvement is 64,516 USD, the return on investment (ROI) is 37.3 years.

Measure 8: The temperatures of regular spaces such as offices, lobby, outpatient clinic and general wards inside the hospital building are increased from 25ºC to 26ºC. The room temperatures of special spaces remain unchanged. Therefore, by this energy saving measure, energy consumption will be 8,342,484 kWh, saving 1.11% of electricity about reduction of 9,022 USD. Since cost of this improvement is 0 USD, the return on investment (ROI) is 0 years.

# 4 CONCLUSIONS

In this study, the building energy software EnergyPlus was used to calculate annual energy consumptions of the hospital building under various energy saving measures. The feasibilities of energy saving measures have been evaluated in terms of annual savings and pay-back period of the investment. The pay-back periods of the investment of energy saving measures such as replacement of a high-performance chiller of 250 RT, increasing outlet chilled water temperature of chillers by 1ºC, decreasing inlet cooling water temperature of chillers by 1ºC, and increasing room temperature of regular spaces by 1ºC are less than 5 years, which are recommended to implement first. By simulations, those analyses could be beneficial to establish a feasible retrofit plan for energy performance of this hospital building.

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