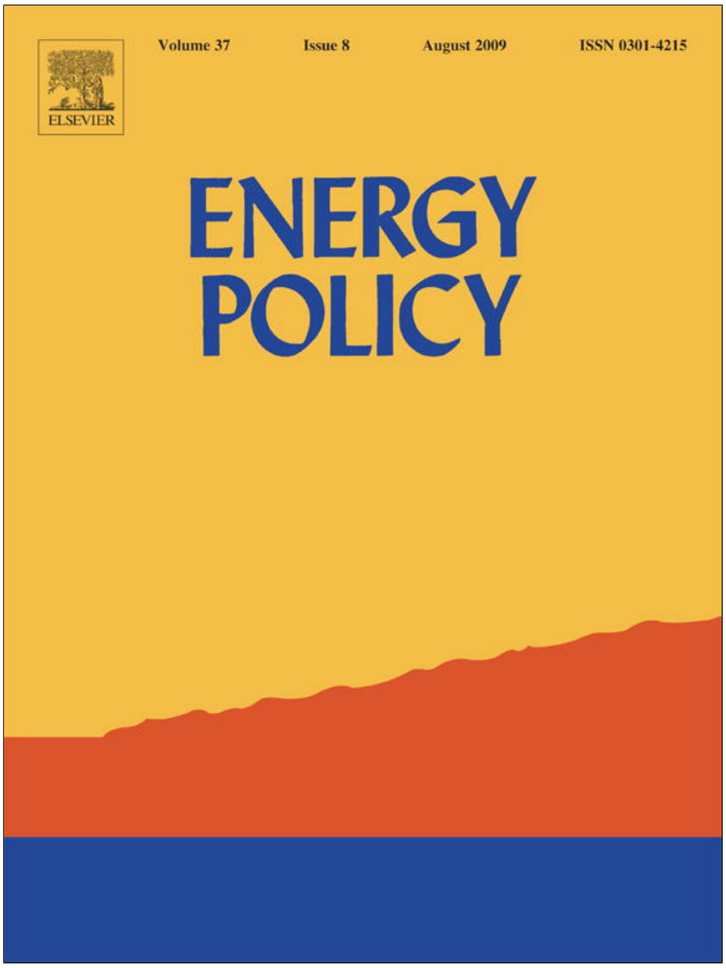
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Conservation vs. renewable energy: Cases studies from Hawaii

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ABSTRACT

State of Hawaii generates about 90 percent of its electricity from imported fossil fuel sources. Thus, there is pressure from both public and policy makers to reduce the State dependency on foreign fossil fuel sources. To this extend, there are incentives created at State and Federal level for both residential and commercial buildings to install photovoltaic (PV) systems. Although such incentives are necessary for long-term objectives, it is shown in this study that retrofitting inefficient old building-equipment is another viable source to reduce the State of Hawaii's electricity demand. Four case studies are presented to illustrate that building-equipment retrofitting is a viable and necessary tool for increasing the energy efficiency of buildings. Each case study presents an equipment retrofit project electricity savings with its payback periods, and compares with equivalent electricity capacity and economics PV systems in Honolulu, Hawaii. The case studies show that energy savings from retrofit projects ranged from 28% to 61% for individual equipment retrofits. These results indicate that equipment retrofitting with energy-efficient alternatives is about 50% or more cost-effective than installing PV systems. This is so even when large renewable energy tax incentives provided by the Federal and State Governments are taken into account.

1. Introduction

The State of Hawaii is a series of islands located in Pacific Ocean with no fossil fuel sources of its own. However, fossil fuels make about 90% of energy consumption in Hawaii (see Fig. 1). Thus, there is a significant pressure from public and policy makers to decrease the State's dependency on fossil fuels. To this extend, the State of Hawaii legislation mandated that 10% of energy should be produced from renewable sources by year 2010 in the State of Hawaii. The State also mandated renewable energy percentage should reach to 20% by 2020 and 30% by 2030. Although, it is desirable to produce energy from renewable resources from both environmental and economical point of views, it requires substantial capital and work force investment. For example, wind energy is one of the accepted sources of renewable energy source in Hawaii. Thus, there is substantial interest in developing electricity from wind energy. To this extend, several commercial companies have made agreement with the State's Electrical Utility Company, Hawaiian Electric Company (HECO), to plant wind turbines to the Islands of Molokai and Maui. The produced electricity will be transferred to the Island of Oahu via undersea cables, which requires substantial capital investment (State of Hawaii and DBEDT). Quite long time is required to repay the invested capital.

While the State of Hawaii's commitments to renewable energy sources is remarkable and forward looking, no such legislative effort is seen in Hawaii to promote and mandate energy conservation. The only incentive provided for energy conservation in Hawaii is through a rebate program provided by the local utility company HECO. As the low-hanging fruit, decreasing the energy consumption via increasing the energy efficiency technology is much desirable, since it reduces the demand on environment and capital investment. To this extend, American Physical Society (APS) published a report documenting that energy efficiency as the cheapest energy source (APS, 2008). Further, the APS states that energy efficiency is necessary for sustainable technology and social development. Therefore, effective policy making is required to mandate energy conservation by commercial and residential buildings.

It is important to evaluate the roles of energy conservation and renewable energy in context with environment and ever-increasing energy demand worldwide. Energy conservation reduces energy demand (energy savings), whereas renewable energy generation is a clean energy source and reduces dependence on fossil fuels, which are finite sources with negative environmental impact. Renewable energy should not be considered as a source to reduce energy demand, because it is harvested energy from the nature (i.e., wind, sun, etc. in broadest terms). Energy demand can be reduced only by addressing energy efficiency through new technologies.

Energy intensity, defined as energy use per capita divided by GDP per capita, or energy consumption per GDP, is another

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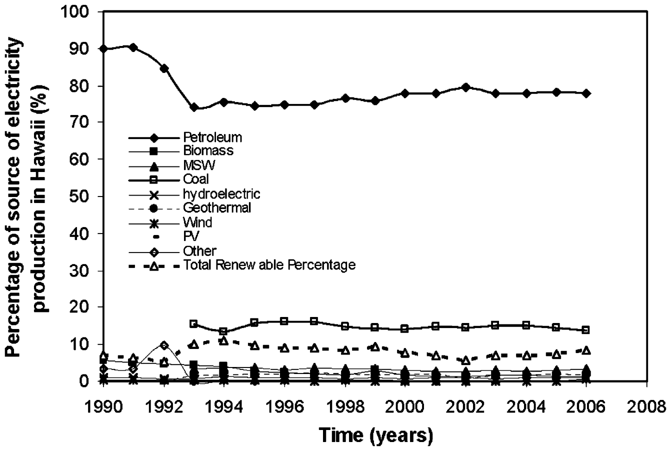

Fig. 1. Sources of electricity production in Hawaii.

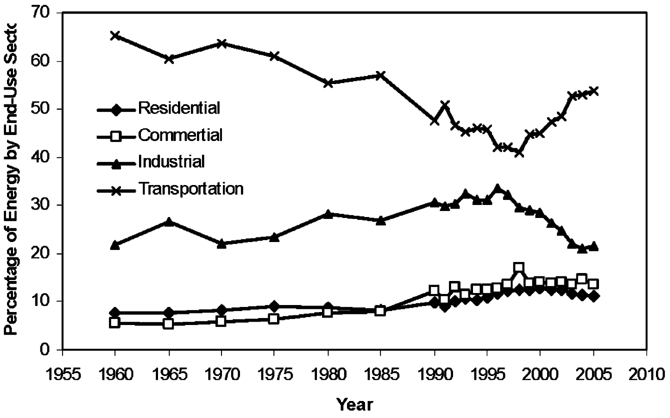

Fig. 3. Variation of energy use by end-sectors in Hawaii.

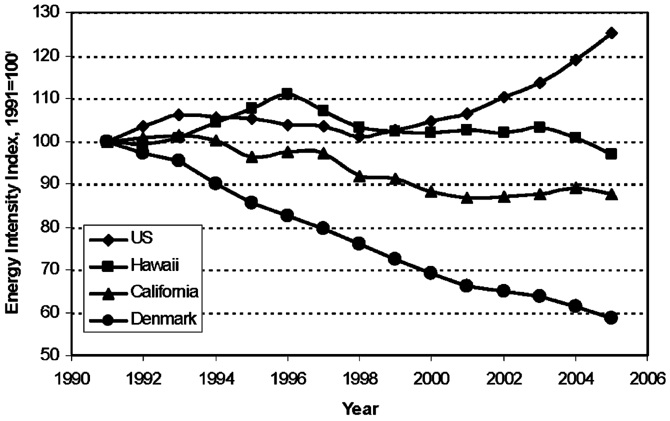

Fig. 2. Comparison of energy intensity index of Hawaii with those of US average, California and Denmark.

measure used to compare the energy consumption and efficiency trends (Brown-Santirso and Thornly, 2006). Energy intensity index is the normalization of energy intensity with respect to certain time. What is desirable by energy conservation is decreasing the quantity of energy usage, while without changing (preferably increasing) the amount of work gained (Suehiro, 2007). Thus, by increasing energy conservation by means of increasing efficiency, it is quite possible to decrease the energy intensity index, which many European countries and California have been successfully doing.

We compared the energy intensity index of Hawaii with those of US average, California and Denmark to determine the relative energy efficiency of Hawaii. Denmark was chosen as she has the lowest energy intensity index in Europe (COP15), and California was chosen as it is the most advanced energy-efficient state in the US. As demonstrated in Fig. 2, energy intensity index of Hawaii increased from 1991 to 2004, when 1991 is taken as the comparison base. On the other hand, the energy intensity index of Denmark continuously decreased over time and reaches 60% of 1991 baseline. The Denmark energy intensity trend is desirable, since it represents both reduced negative impacts of energy generation on environment and increase in capital income per person. In this aspect, Fig. 2 reveals that energy consumption in Hawaii does not cause an increase in income per capita. However, in contrary to US average and Hawaii, the energy consumption rate of California and Denmark shows parallel with increase in capital income per person. Thus, as suggested by the report published by American Physics Society decreasing energy consumption by increasing the energy efficiency technology is a very effective way of increasing the income per capita, while keeping the sustainable development without adversely affecting the environment.

Despite tremendous benefits of energy conservations and its effect on productivity and GDP as outlined in Fig. 2, both Federal and State governments focused on energy production from renewable sources. For producing energy from renewable sources, both Federal and State governments created incentives to develop and install renewable energy sources such as PV systems. For example, US government provides 30% tax credit for new PV installations in commercial and residential buildings. Additionally, the State of Hawaii provides 35% tax credit up to $500,000, whichever is less, for new PV installation. In other words, taxpayers subsidize the PV installation in both Federal and State government level. Although these incentives are necessary for long-term objectives, as will be demonstrated through case studies presented here, reducing energy consumption via increasing equipment efficiency are much more sensible and effective first steps in short term to reduce dependence on fossil fuels. Further, as reported by Yalcintas and Ozturk (2007) and Yalcintas (2006, 2008), energy savings through building-equipment retrofits is much more cost-effective than installing renewable energy sources including PV systems. This is especially important for Hawaii, being a tropical island, where for example, air-conditioning is needed all year around, and 65% of the produced electricity is consumed by buildings. Further, as shown in Fig. 3, both residential and commercial energy consumption increased over time and reached about one quarter of total energy consumed in Hawaii in the past years, in which most of the electricity is consumed for lighting and air-conditioning.

2. Energy conservation potentials by building-industry

According to the US Energy Information Administration, about 39% of the US energy usage is by commercial and residential buildings. Energy is used in buildings mainly for space heating and air-conditioning, domestic water heating, lighting and plug loads including computers, other electronics and household-type appliances. Average lifespan of buildings are long when compared to other energy use sectors, such as transportation, industrial, etc. Therefore, most often energy using equipment in buildings needs replacement several times over the lifespan of a building. However, the building-equipment replacement is often postponed as long as possible to avoid associated replacement costs. This penalized building's energy efficiency, since most often new equipment with new technologies is more energy efficient when compared to old equipment or old technologies.

Energy conservation in building-industry refers to most often replacement or retrofit of old and inefficient equipment with new energy-efficient technologies. Buildings can conserve/save energy in the range of 15%–30% through retrofit projects. Several studies focused on developing models to predict building-energy savings from retrofit projects (Kissock et al., 2003; Soderegger, 1998 and Yalcintas, 2006). There are additional studies that correlate whole building energy use with climate data and other building variables, such as building occupancy rate, plug load density and HVAC equipment (Neto and Fiorelli, 2008 and Pedrini et al., 2002).

Through the past few years, a great effort is made by governments to develop and promote renewable energy technology. Federal and State tax incentives are available to individuals or companies who invested/installed certain renewable energy generators such as photovoltaic (PV) panels or wind turbines. While, this is an important step in promoting environmentally friendly renewable energy sources, improving efficiency of energy using equipment through retrofits have not gained such publicity or interest. Incentives for equipment retrofit projects are generally limited to rebate programs by local electric utility companies, which are nowhere close to the tax credits provided for renewable energy projects in the US. The study presented here shows energy conservation as an important essential step of energy independence from fossil fuels.

3. Method of collecting and analyzing data

In this study, a return on investment comparison is made between building-energy conservation and renewable energy. Several case studies are presented where actual energy conservation retrofit project was implemented and energy savings were observed. A hypothetical condition was created where photovoltaic panels would be installed to produce the power otherwise saved by the energy conservation retrofit project. The cost of installing the equivalent capacity PV system was compared to the cost of the retrofit project.

In order to determine energy savings from retrofit projects, pre-retrofit and post-retrofit power monitoring data was collected for a period of time, usually in the order of weeks. Power monitoring is usually recorded from the actual equipment to be retrofitted. However, if the retrofit project covers several pieces of equipment, or if it affects indirectly the energy usage of other equipment, power recording can be taken from several pieces equipment, or from the equipment that shows best the energy impact of the retrofit project. In the second step of the energy savings analysis of the retrofit project, the pre-retrofit and post-retrofit power measurements were reflected to the entire year. If the retrofit project is related to space heating or cooling, yearly energy usage is calculated either through integrating weather variables throughout the year or by adjusting the monitored data with a seasonal diversity factor. Yalcintas (2006) presents an artificial neural network (ANN) based method that uses weather data in estimating energy savings from retrofit projects. The pre- and post-monitoring periods in the case studies presented in this paper corresponds about the same season of the year, mostly about one to two months apart in the same season. In addition, measurements were taken during the mild seasons in Hawaii, and air-conditioning is provided throughout a year in Hawaii. Therefore, in the yearly energy estimates of pre- and post-retrofit projects no seasonal diversity factor is used.

The retrofit projects presented in case studies belonged to various buildings through Hawaii. The authors were involved with the retrofit projects either as third party reviewers for utility company's rebate program, or performed actual engineering design of the retrofit projects. The case studies were selected from a pool of energy retrofit projects that reflected best the most common energy conservation project in Hawaii. Because of the sensitivity of the data presented, we have omitted any information that might reveal the identity of facilities in the case studies presented here. Furthermore, since photovoltaic-based renewable energy technologies are most often used by commercial or residential buildings, the case study renewable energy comparison presented in this paper are based on PV renewable energy source.

4. Case study 1: integrating energy management systems in hotel rooms

The energy measurement data used in this case study belongs to a hotel in Honolulu, Hawaii. The hotel had about 2200 guestrooms, as well as a number of restaurants, meeting rooms and retail stores. The hotel was served with two 1400 ton capacity chillers. Only one chiller was operational most of the time, the second chiller served as back-up. The particular retrofit project in the hotel consisted of installing energy management systems in the hotel rooms and integrating variable frequency drives (VFDs) on the air-handling units. A number of air-handling units having varying fan motor sizes from 5 HP (3.73 kW) to 25 HP (18.65 kW) served the restaurants, meeting rooms and other common areas. The hotel rooms had fan coil units with cooling capacities ranging from 0.5 (1.76 kW) to 1.0 ton (3.52 kW). The energy management system monitored the occupancy in the hotel rooms and the open/closed state of the balcony sliding doors. If the sliding doors were left open more than five minutes, the chilled water supply valve to the fan coil unit was turned off, and the fan cycle was left on. If no occupancy was sensed in the room for more than 30 min, the room temperature set point was increased to 30.5 °C (87 °F), from a normal occupancy set point of 24 °C (75 °F). Pre- and post-retrofit measurements were taken from chillers for a total of about three weeks. Each measurement included hourly electricity demand (or kW) recordings from the chillers. In addition to the chillers, the building saved energy from reduced chilled water pump operation and air-handling unit operations with new VFDs. However, electricity measurements from the chilled water pumps and air-handling units were not available. Therefore, only the energy savings from the chillers were included in this analysis.

Fig. 4 shows the chiller power usage during the pre- and post-monitoring periods. Although no retrofit took place on the chillers themselves, the reduced cooling demand due to the new energy management systems in the hotel rooms reflected on reduced power demand on chillers. From the measurements, average power demand for chillers in pre-retrofit period was 539 kW and in post-retrofit was 388 kW. The difference of 151 kW per hour is the savings from the energy management system retrofit. The performance of chiller power was followed though electricity bills, which showed that the electricity demand remained the same for all practical purposes.

For 24 h per day continuous air-conditioning demand (for Hawaii) 151 kW per hour would correspond to about 1323,000 kWh per year energy savings, or $264,550 per year with $0.20 per kW average electricity rate in Honolulu. The energy management system installation cost was about $500 per room, or $1125,000 total. The payback period for this retrofit project was about 4.3 years.

If the hotel had chosen to install renewable energy system instead of improving energy efficiency of its air-conditioning equipment, it would require about 725 kW capacity photovoltaic system to create same energy savings effect. The 725 kW PV system size is determined by five hours per day full capacity equivalent energy generation of a PV system in Hawaii (151 kW times 24 h per day divided by 5 h per day PV full capacity energy generation). With a $10 per Watt installation cost of PV systems in Hawaii, a 725 kW PV system would cost about $7250,000. The US government provides 30% tax credit for new PV installations in commercial facilities. Additionally, State of Hawaii provides 35% tax credits up to $500,000, whichever is less. If these tax credits are considered, actual cost of installing 725 kW PV system will be about $4,575,000. The payback period for the PV system would be about 17.3 years. Additionally, a 725 kW PV system would need about 725,000 square feet open area, which is very hard to find at an urban location like Honolulu. For this particular hotel case, the total roof area is about 30,000 square feet, which shows that it would be physically impossible to use the roof for the 725 kW capacity PV system.

The Case study 1 retrofit energy saving and cost analysis, as well as the alternative PV system analysis are summarized in Table 1. When one compares building-energy-conserving equipment retrofit vs. installing renewable energy systems to buildings for additional power, one can clearly see outstanding benefits of energy conservation in buildings through new energy-efficient technologies.

5. Case study 2: replacement of existing cooling towers in a hotel

This retrofit project was for another hotel building with 520 guest rooms. The hotel was served with three 500 ton capacity chillers and with three 500 ton cooling towers, each cooling tower consisting of two cells. Only two chillers were operational most of the time. The third chiller served as a back-up chiller. Depending on part load or full load cooling demands, cooling tower cells were activated; as a result two to four cooling tower cells were operational at a time. The particular retrofit project involved replacing two old cooling towers with new ones. Old cooling towers each had 50 HP constant speed fan motors. The new cooling towers had equal capacity fan motors; in addition, the fan motors were equipped with variable frequency drives. Electricity usage data was recorded from the old cooling towers for a three-week-long pre-retrofit monitoring period, and from the new cooling towers for a ten-day-long post-retrofit monitoring period. Each measurement included hourly electricity demand (or kW) recordings from operational chillers and cooling towers.

Fig. 5 shows the cooling tower power usage pre- and post-monitoring periods. Average power demand for cooling towers in pre-retrofit period was 44 kW and in post-retrofit was 17 kW. This retrofit project saves about 27 kW per hour, which would correspond to about 236,500 kWh per year energy savings, or $47,300 per year. The installation cost for the two new cooling towers was about $340,000 total, and the payback period was about 7.2 years.

Additionally, chiller efficiency increased due to efficient cooling operations; therefore, chillers also realize energy savings. However, pre- and post-period chiller power monitoring data is not available to present in this paper, therefore, chiller energy savings is not included in this Case study 2.

If the hotel installed renewable energy system instead of improving cooling tower energy efficiency, which meant replacing old inefficient cooling towers with new efficient equipment in this case, it would require about 130 kW capacity photovoltaic system to create same energy savings effect. Similar to Case 1, the equivalent PV system size is determined by five hours per day full capacity PV electricity generation in Hawaii. The 130 kW PV system would cost about $1,300,000. When the US and Hawaii tax credits are deducted, the resulting cost of PV system becomes $455,000, with a payback period of 9.6 years. This is less than the equipment retrofit project cost that would conserve the same

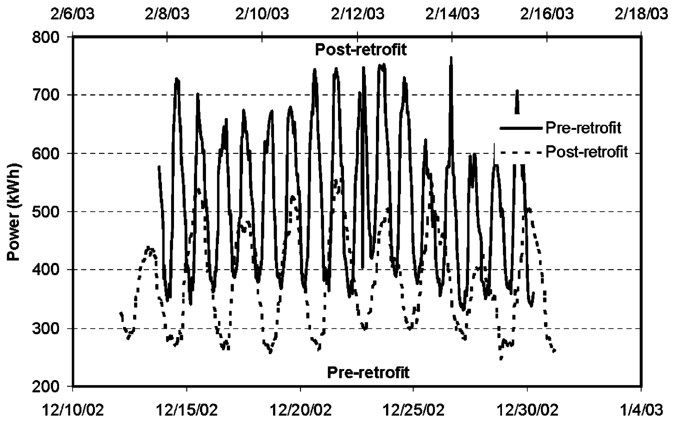

Fig. 4. Case 1 Pre- and post-retrofit period chiller power monitoring.

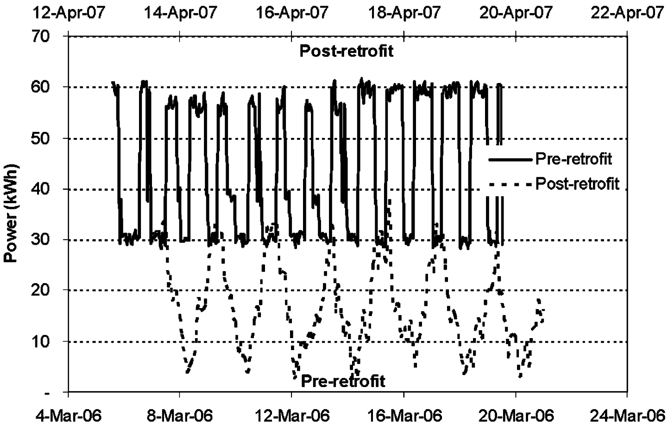

Fig. 5. Case 2 Pre- and post-retrofit period cooling tower power monitoring.

Table 1
Comparison of energy savings and cost of retrofitting and installing PV systems[a].

	Energy usage before retrofit (kW)	Energy usage after retrofit (kW)	Energy saving (kW)	Energy saving (%)	Retrofit cost ($)	PV cost without federal and state incentives ($)	Payback period for retrofitting (Years)	Payback period after deducting federal and state incentives (years)
Case study 1	539	388	151	28	1,125,000	7,250,000	4.3	17.3
Case study 2	44	17	27	61	340,000	1,300,000	7.2	9.6
Case study 3	152	96	56	37	420,000	2,690,000	4.3	14
Case study 4	145	70	75	51	90,000	2,020,000	<1	20

[a] Calculations are based on a $10 per Watt installation cost of PV and $0.20 per kW of electricity, which are the average costs in Honolulu, Hawaii in 2006 through 2008.

amount of electricity. The energy and payback analysis for Case 2 is listed in Table 1. Additionally, a 130 kW PV system would need about 130,000 square feet open area. For only about 20,000 square feet available roof space, the hotel actually needs to use other available open real estate areas to locate the PV panels.

This case study also proves that investment on improving the energy efficiency of building-equipment is much more sensible than installing renewable energy system, even when all federal and state tax credits are included in favor of renewable energy system installation.

6. Case study 3: supermarket air-cooled condensing unit (ACCU) retrofits

This retrofit project included replacement of existing three air-cooled condensing units with two new ACCU units at a supermarket in Honolulu, Hawaii. ACCUs served as outdoor heat release units for the supermarket refrigeration cases. One of the existing small ACCUs was maintained.

The pre-retrofit power measurements consist of power recordings of existing compressor racks and pre-retrofit air-cooled condensing units that served the supermarket refrigeration cases from August 20, 2007 to September 05, 2007. The post-retrofit power measurements consist of power recordings for existing compressor racks and post-retrofit air-cooled condensing units, from November 06, 2007 to November 30, 2007. Although the retrofit project is for air-cooled condensing units replacement, power measurements from existing compressor racks were also collected, since the air-cooled condenser performance affects the compressor rack efficiency in general.

Fig. 6 shows the pre-retrofit power measurements and post-retrofit power measurements from old and new ACCUs and existing to remain supermarket refrigeration case compressor racks. From the measurements, average power demand for ACCUs and compressor racks in pre-retrofit period was 152 kW and in post-retrofit was 96 kW. This retrofit project saved about 56 kW per hour; corresponds to about 490,500 kWh per year energy savings, or $98,000 per year with uninterrupted operation throughout the year. The installation cost for the two new ACCUs was about $420,000 total, with 4.3 years of payback period.

If the supermarket had chosen to install renewable energy system instead of improving energy efficiency of its refrigeration case cooling equipment, it would require about 269 kW capacity PV system to create same energy savings effect. A 269 kW PV system would cost about $2,690,000. If the US Federal and Hawaii tax credits are considered, actual cost of installing 269 kW PV system will be about $1,383,000. Payback period of the PV system installation cost is about 14 years. Additionally, allocating roof or lawn space for the PV panels still remains a challenge for this case study as well. The summary of the analysis presented in Case study 3 is listed in Table 1.

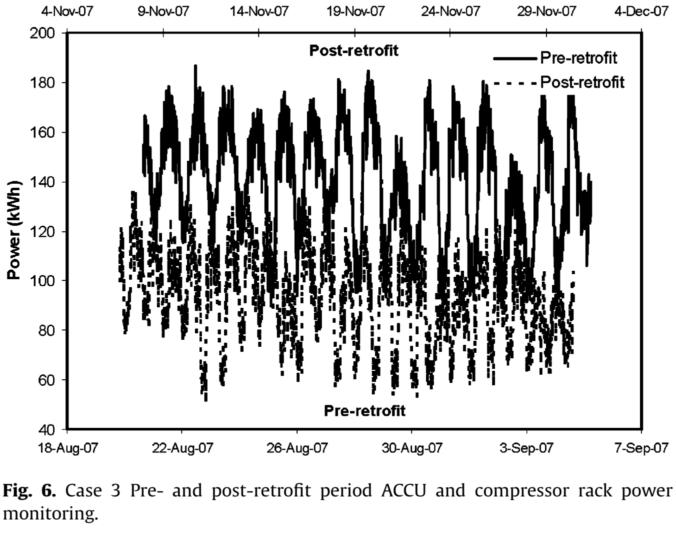

Fig. 6. Case 3 Pre- and post-retrofit period ACCU and compressor rack power monitoring.

7. Case study 4: manufacturing facility lighting retrofits

This retrofit project included removal of existing 316 metal halide lighting fixtures and installation of 299 of 4L-T5HO new lighting fixtures with new ballasts, at a manufacturing facility in Honolulu, Hawaii. Each of the new 4L-T5HO fixtures had four lamps. Whereas, existing metal halide fixtures had single lamp. Majority of the manufacturing facility had lighting on 24 h Monday through Friday, since it based its operation in three work shifts throughout the day and night. The plant was operational 12 h on Saturdays and the lighting was turned off on Sundays and Holidays. Metal halide lamps were rated at 400 W each and the new 4L-T5HO lamps were rated at 54 W each. Additional 58 W electricity was used per existing metal halide fixture ballast, whereas 18 W electricity was used per new 4L-T5HO fixture ballast in these lighting retrofits. The new ballasts are electronic ballasts that use low electricity compared to magnetic ballasts.

No monitoring took place for this retrofit project, since energy demand for lighting is relatively constant when compared to an air-conditioning system, which greatly varies by weather conditions.

In this retrofit analysis, rated power demand for existing lighting fixtures and ballasts were calculated and compared against retrofitted new lighting fixtures and ballasts. The total power demand for lighting in pre-retrofit period was about 145 kW and in post-retrofit period was about 70 kW. The retrofit project created about 75 kW power savings. For the building lighting operation schedule, the building would save about 514,800 kWh per year of electricity, or about $103,000 per year with $0.20 per kW average electricity rate in Honolulu. The installation cost for the new lighting system was about $90,000, which could be recovered in about a year.

Again, had the manufacturing facility preferred to install PV system instead of improving the building's energy efficiency, for an equivalents energy savings effect, they had to install 360 kW PV system, and pay about $2,020,000 after Federal and State tax incentives. The recovery period for this investment would be about 20 years.

8. Discussion

Table 1 summarizes the energy usage before and after building-equipment retrofits for each Case study, including the cost of equipment retrofit, cost of installing comparable PV systems, and payback periods for equipment retrofits and comparable PV systems. As demonstrated in Table 1, energy savings from retrofit projects ranged from 28% to 61% for individual equipment retrofits, depending on the retrofit project. Table 1 further shows that equipment retrofitting with energy-efficient alternatives is more cost-effective than equivalent PV systems, even when large renewable energy tax incentives, provided by the Federal and State Governments, are taken into account, which is basically paid by taxpayers. Thus, the comparison in Table 1 strongly suggests that building-equipment retrofitting with energy-efficient technologies should be required for existing large-scale buildings to increase their energy efficiency. It should be emphasized that incentive programs for producing energy from renewable sources should continue as a long-term objective. What is advocated here is that it should be a requirement for large-scale buildings, including residential, commercial and industrial facilities, to retrofit existing inefficient building-equipment with energy-efficient technologies before installing PV or similar renewable energy systems. Further, it should also be noted that sometimes it is not possible to install PV systems into large buildings in urban settings such as Honolulu, Hawaii. Whereas, retrofitting building-equipment with energy-efficient alternatives are always possible.

9. Conclusion

While renewable energy sources are viable options for sustainable electricity generation, energy conservation remains a priority to make the renewable energy investment meaningful. Usually investments for lighting retrofits are recovered within a year or two for regions with electricity rate ranging from $0.15 to $0.25 per kW. The HVAC-type retrofits tend to cost more, with payback period ranging from three to ten years subject to similar electricity rates. If a building has implemented all possible energy-conserving measures, then investing on renewable energy generation onsite becomes a sustainable and economical alternative. As the case studies presented, payback periods for PV systems ranging from 5 years to 20 years are still attractive investment options in addition to their environmental benefits. However, renewable energy should be considered only after all building efficiency upgrades are fulfilled. Thus, we recommend that the Federal and State policy makers adapt policies to require equipment retrofitting mandatory for any incentive payments for renewable energy sources such as PV systems as all incentives are paid by tax payers.

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