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RESEARCH ARTICLE

Rooftop photovoltaic (PV) systems for industrial halls: Achieving economic benefit via lowering energy demand

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Abstract
Industrial halls are characterized with their relatively high roof-to-floor ratio, which facilitates ready deployment of renewable energy generation, such as photovoltaic (PV) systems, on the rooftop. To promote deployment of renewable energy generation, feed-in tariff (FIT) higher than the electricity rate is available in many countries to subsidize the capital investment. FIT comes in different forms. For net FIT, in order to maximize the economic benefit, surplus electricity generation at each hour is desirable.
One way to achieve surplus electricity generation is by increasing generation capacity, which is synonymous to higher capital investment. In fact, surplus electricity generation can also be achieved by lowering the energy demand of the building. This particularly the case for industrial halls, which are usually subject to high energy demand for space conditioning in order to remove the excess heat gain due to the many power-intensive processes.
Building energy performance simulation tools can be used to explore the different building design options that could lower the energy demand. In this paper, single-objective optimization on investment return will be deployed to study the cost effectiveness among different options in lowering energy demand. It will be demonstrated with a case study of a warehouse.

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1. Introduction

In the last decade, global warming, due to emissions from fossil fuel based energy generation, has become a concern. Electricity generation in 2008 from renewable energy sources is estimated at 16.7% in Europe (Eurostat, 2011a), and 18.7% around the globe (IEA, 2010). In 2007, the EU-wide directive (EU, 2011a) was set such that power from

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renewable energy sources shall comprise at least 20% of total energy generation by 2020 for the European Union as a whole. Each country has also set a target, for example, 17% for Italy, which is more than triple of the 2005 percentage of around 5% (REN, 2010).

The industrial sector is one of the heaviest consumers of energy. In Europe, this sector consumed 24% of the total energy consumption in 2009 (Eurostat, 2011b), while in the United States, the sector consumed 32% in 2009 (LLNL, 2010). Some of the energy from this amount was consumed in the manufacturing processes and for lighting, while much of the rest was spent to provide space conditioning to maintain the building within a reasonable or legally allowable temperature range. Since the manufacturing processes generate large amount of heat as a by-product, buildings in general require cooling to remove the excess heat gain.

Industrial halls are characterized with their relatively high roof-to-floor ratio as compared to other types of buildings of similar total floor area. This makes it quite beneficial to incorporate renewable energy producing components into the building design by taking advantage of the proportionally large rooftop area, which in most cases does not serve any particular purpose. Photovoltaic (PV) systems were posed as a promising technology to produce renewable energy. PV systems could be readily deployed and attached to the rooftop with no special requirement on or alteration to the building design. In addition, industrial halls are mainly situated in sparsely populated areas with open fields in which the performance of PV systems is not hampered by shading of surrounding buildings. Therefore, grid-connected solar PV systems could be one of the options.

However, at the current price level, deployment of PV systems is synonymous with high capital investment, which is not likely to be covered by savings in electricity cost at the current electricity rate. In order to promote wider deployment of PV systems in the hope that wider adoption will lower the cost of deployment in the future, government policies come in different forms of economic incentives to compensate the high investment cost. Out of these, feed-in tariff (FIT) is the most common form of such incentives (EEG, 2007).

The evaluation of the economic benefit requires the consideration of the different feed-in tariff schemes and the various economic parameters, such as electricity rate, discount rate, and others, which are the result of market forces rather than factors that the building stakeholders have control of. On the other hand, the building stakeholders could play a more active role in the design of the buildings. With better building design, energy consumption will decrease. As a result, electricity generation shall satisfy the lowered consumption for more hours such that a smaller-capacity PV system will still be economically viable (or a larger-capacity PV system will yield higher benefit). Lee et al. (2011) presented the cost–benefit analysis under such premise.

Current design practice in evaluating the capability of PV systems in meeting a building's energy consumption is to assume the same daily consumption load profile for the whole year or to adopt an annual total consumption (CEC, 2001). Little of the literature studying the performance of PV systems actually conducts an hourly assessment on matching the generation to the demand profile.

To fill the gap, this paper will assess the economic performance of PV systems based on computational simulation of both the energy generation capability of the PV system and the energy consumption of the industrial hall building. A notable portion of the energy consumption, that is the cooling load of the building, is greatly affected by the weather/solar insolation of the location. This is particularly problematic for industrial halls with high heat gain from the power-intensive manufacturing processes since most conventional means of heat removal (forced ventilation, cooling tower, etc.) are highly sensitive to the time-varying ambient environment.

In this paper, the focus is to find the optimized building design options on demand side parameters that will maximize the economic benefit of the PV system investment. The energy consumption due to the demand of space conditioning will also be presented, since design options that yield the maximum economic benefit might not consume the least energy, or vice versa.

A case study of a typical industrial hall is presented, which will be investigated with a representative heat gain that is typical for the case of a warehouse. This paper presents some of the results of an on-going project Sustainable Energy Producing Steel Frame Industrial Halls, which also studies other operation energy related aspects of steel frame industrial halls.

2. Optimizing economic benefit of rooftop PV system through lowering energy demand

This paper is based on the cost–benefit analysis of Lee et al. (2011), in which the monetary return due to electricity generation of PV system (based on savings in energy cost or income from selling of the exported electricity at FIT), is stacked against the annualized cost of the PV system investment. That analysis was demonstrated with a case study of industrial hall, which was conducted for two locations—the German city of Düsseldorf that represents a moderate climate, and the Italian city of Palermo that represents a dry subtropical climate with higher solar insolation for most hours; and was investigated for different process energy scenarios (different heat gains). The result of that particular case study indicates that under the most stringent net FIT scheme (as compared to the other two commonly deployed but more investor-friendly schemes—gross FIT or own consumption FIT), only a warehouse located in Palermo with PV system nearly covering the whole roof yields net benefit. This paper bases upon the assumptions and findings of that case study, and further explores the economic benefit of rooftop PV system through lowering the energy demand by optimizing the building design based on demand side parameters.

2.1. Case study building

The case study adopts the same hypothetical warehouse proposed in the previous study and investigates for the location of Palermo.

2.1.1. Warehouse

The case study building, which represents a typical warehouse, is of rectangular shape measuring 80 m width $\times$ 136 m depth $\times$ 6 m height. Equipment (computer, forklift, etc.) consuming 5 W/m^2 of electricity is assumed. And in order to maintain a lighting level of 500 lx (CEN, 2002), fluorescent