ISBN: 978-84-697-1815-5

Life Cycle Assessment on the installation of BIPV on Green Energy Housing Building in Taiwan by Life Cycle Carbon Minus method

Bin Feng Liu[1], Shin Ku Lee[2], Chun Ta Tzeng[3], Heng Zhang[4], Yen-Jong Chen[5]

1. Department of Architecture, National Cheng Kung University
2. Research Center of Energy Technology and Strategy, National Cheng Kung University
3. Department of Architecture, National Cheng Kung University
4. Department of Architecture, National Cheng Kung University
5. Research Center of Energy Technology and Strategy, National Cheng Kung University

Abstract: *It has been a few decades for the conflicting argument between the economic development and environmental protection in Taiwan. Excluding the political standpoints, the main argument would be the allocation of the regional resources, including the spatial plan of industrial development, and area of sensitive environment where need to be protected. The scientific approaches to build up a comprehensive database of geographic and demographic data embodies a spatial plan brings the argument to the stage of the regional planning with a whole vision of regional development. On the other hand, the fast progress of the renewable energy technology would also play an important role in the regional planning and carbon minus. In this study, we focus on the living energy consumption, instead of the discussion of industrial energy saving. We select the area of Taijing, a seaside area in Tainan City, currently having rich ecological resources, high technology industries, and local fish farms. Thus, the energy saving assessment based on the LCCM approaches is conducted. This study assumes a PV panel installation site first, and then estimates the carbon dioxide emissions of product manufacturing stage and delivery stage, respectively. Then numerical simulations are conducted to predict the carbon dioxide emissions in building operations and decommissioning stage. Finally, the life cycle assessment of BIPV applied to the building is completed. The evaluated result indicates that CO_2 emissions from PV roof decrease with the surplus energy for operation and fall below zero after 2.5 years. This result implies that this PV roof can become a carbon minus a facility after 2.5 years-old of building and contributes to the decrease of carbon emissions of the whole building.*

Keywords **：*LCCM (Life cycle Carbon Minus), Living Culture, Green Energy Building , BIPV***

1. INTRODUCTION

Emissions of greenhouse gases (GHG), such as carbon dioxide, nitrogen sulfide, and fluorine carbonate, which are related to the burning of fossil fuels, are adversely affecting the environment and leading to a rise in global temperature. Therefore, many researches devoted to investigate the optimal energy policy or strategy to resolve the issue of the climate change. According to the statistics from NOAA ESRL Global Monitoring Division, the trend of the global CO_2 emission is increased, the global CO_2 emission is 396.16 ppm in 2013, and the

ISBN: 978-84-697-1815-5

global CO_2 emission is increased 398.72 ppm in 2014 (as shown in Imagen 1). On the other hand, according to the statistics from the IPCC [1, 2], the building sector consumes 40% global energy and discharges CO_2 to 36% (as shown in Imagen 2). GHG emissions from buildings can be decreased by three major ways: by reducing energy consumption in buildings, by switching to low-carbon fuels including a higher share of renewable energy, and by controlling the emissions of non-CO_2 GHG gases.

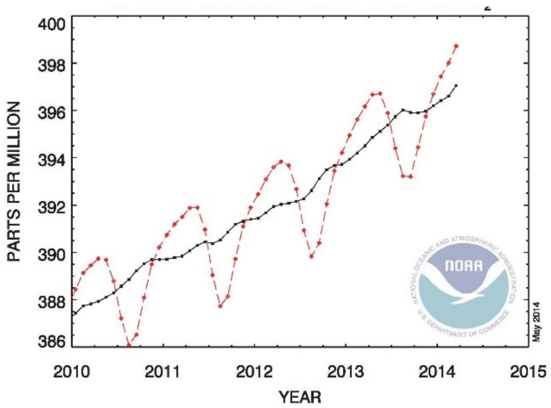


Imagen 1 Recent Global Monthly Mean CO_2

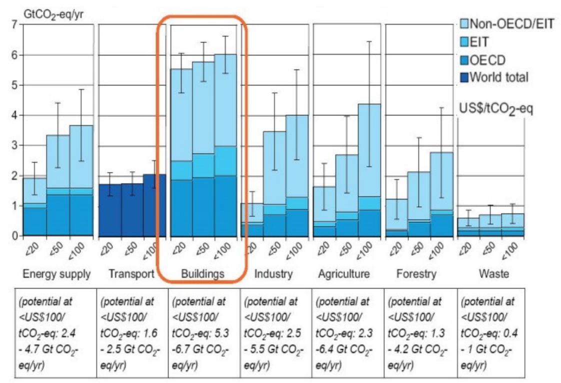


Imagen 2 The building sector offers the largest low-cost potential in all world regions by 2030.

The Tainan area contains not only a wealth of ecological, geographical conditions and historical culture, but also rich in a diversity of renewable energies. That includes the more than 2,400 hours of annual sunshine, especially in the south part of Taiwan, to provide the sufficient source of solar power, and strong offshore wind fields around the west coast, and also ocean energy and other natural resources. All of the above conditions are conducive to the development of ecological building. In order to achieve the long-term target of sustainable green building and low-carbon city in Taiwan, it is critical to reduce energy consumption from the residential sector through promoting the further energy conservation and renewable energy in houses. However, it has been a few decades for the conflicting argument between the economic development and environmental protection in Taiwan. Excluding the political standpoints, the main argument would be the allocation of the regional resources, including the spatial plan of industrial development, and area of sensitive environment where need to be protected. The scientific approaches to build up a comprehensive database of geographic and demographic data embodies a spatial plan via GIS mapping of development areas and environmentally protected areas, together with some necessary infrastructure construction. That would bring the argument to the stage of the regional planning with a whole vision of regional development.

According to the analysis of climatic parameters in Tainan, following building tactics are proposed in our previous study [3]. These proposed tactics are described as follows in detail: (1) Building mass layout: We design the south faced building with the extension of east-to-west direction in order to increase ventilation ability; (2) Natural ventilation: In order to

ISBN: 978-84-697-1815-5

enhance the ventilation efficiency, it is proposed to increase the length of the Taijiang House in the east - west direction and to narrow its length in the south-north direction. In addition, the interior partitions parallel to the wind direction can also enhance the efficiency of natural ventilation; (3) Photovoitaic roof: In Taiwan, the optimum roof pitch is at an angle of 23° above horizontal, facing due South. It is proposed to extend the roof area of Taijiang Building for generating the largest amount of electric power by Photovoitaic panels; (4) Hi-thermal capacity building material: For decreasing the indoor temperature variation and improving the thermal comfort in a building, it is proposed to install the hi-thermal capacity building materials, which absorbs and retains the heat at day and then release it slowly at night; (5) Rainwater storage tank: If the rain is collected through the roof and transported by pipeline to underground rainwater storage tank, 400L rainwater is expected to be installed in underground storage tanks. And, the rainwater collected can be used for cleaning and the use of the toilet flush.; (6) Sunshading board design: The proper angle and depth of the sunshading board can be found in the solar projection. And the angle and depth of the shading board change with the seasons and sunlight directions; (7) Mobilization: We conduct a concept of mobilization into construction with the experimental example "Taijiang House". And, this concept helps to make a revolution and turns modularized building components into industrial production through the implementation of "Taijiang House"; (8) Local culture of Taijiang: A semi-outdoor space is designed beside the entrance of Taijiang House in order to imitate Taijiang local squatter huts and provide residents a comfortable open space to communicate and take a rest. [3]

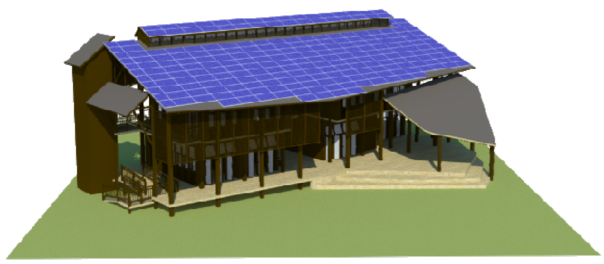


Imagen 3 The illustration of Taijiang House

The concept of a Net Zero Energy Building (NZEB), one which produces as much energy as it uses over the course of a year, recently has been evolving from research to reality. As a result of advances in construction technologies, renewable energy systems, and energy efficient systems, creating Net Zero Energy buildings is becoming more and more feasible. In order to design the Taijiang House as a net zero energy building, the LCCM (Life cycle Carbon Minus) assessment of BIPV roof installed on the Taijiang House Is proposed in this study.

2. RESARCH METHODS

The concept of LCCM (Life cycle Carbon Minus) House was proposed by Building Research Institute, Japan [4], in order to achieve the long-term CO_2 emission target. LCCM method is used to evaluate a house which has a long service life, emits the least amount of CO_2 for constructing the house, using the house and disposing of the wastes, creates recyclable energy by using solar power generation, etc., and results in a negative life-cycle

ISBN: 978-84-697-1815-5

CO_2 emission balance even with the CO_2 emission during the construction included. Imagen 4 indicates that CO_2 emissions from conventional houses continue to increase the longer they are operated. In contrast, CO_2 emissions from LCCM houses decrease with the surplus energy for operation and fall below zero after a period of years, although they rose slightly at the time of renovation.

The following methods are reducing the CO_2 emission to being negative progressively: A. During planning, constructional period, reducing the amount of the CO_2 emission until the building is finished; B. During using period, to use energy efficient facilities for saving energy to reduce the CO_2 emission; C. During using period of LCCM House, the CO_2 emission will be negative because of the building generates the renewable energy by itself; D. Increasing the useful life of the building and reducing the time of the renovations to reach the purpose of reducing CO_2 emissions (as shown in Imagen 5).

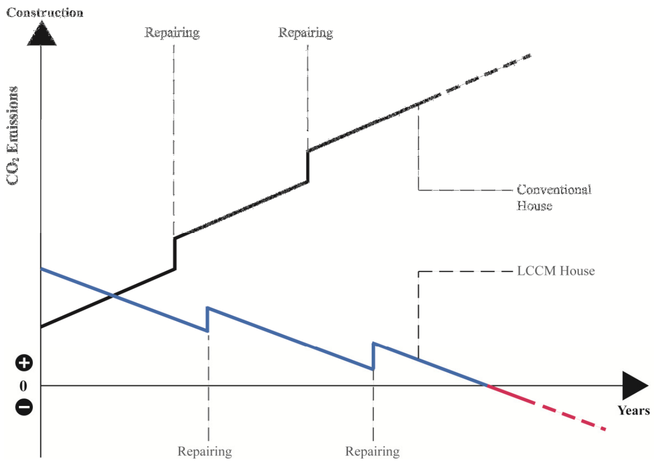


Imagen 4 LCCM House

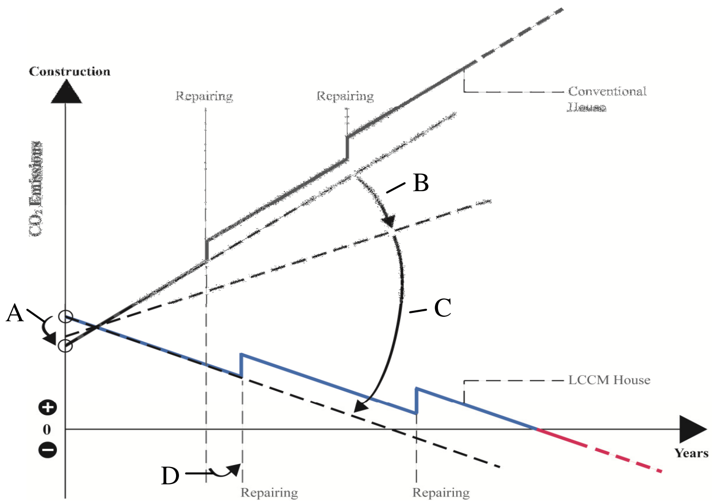


Imagen 5 Carbon Negative by LCCM Housing

Specifically, considerable reduction of energy consumption in the stage of operation and introduction of solar power generation exceeding the consumption make it possible to counterbalance the CO_2 emissions from construction. As well known, computer simulations

ISBN: 978-84-697-1815-5

have been shown to be an effective way to evaluate the energy performance of buildings. The computer simulation assessment by the “Autodesk Ecotect Analysis” simulation software carried out in this work analyzes the energy and electrical generation performance of whole demonstration house integrated with the BIPV roof system. In order to find the annual electrical power generation of the BIPV roof system, we build a BIPV simulation model to simulate the performance of electrical power generation in this study. The simulation model is then used to compile and throughput each electrical power generation conditions for the Taijiang Green Energy Building design.

The simulation model is based on the average weather data for Tainan over the last 10 years (2002-2012; Central Weather Bureau, Taiwan). The computational simulation control factors include the solar azimuth, the building location, distribution of solar irradiation, temperature variation, and shading of the Taijiang Green Energy Building.

3. RESULS AND DISCUSSION

The CO_2 emission of two types of poly-crystalline PV module during the material and manufacturing period are obtained based on ISO 14067. The basic information and CO_2 emission of these two products are shown in Table 1. The size and weight of these products are similar, but the amount of CO_2 emission is different. Table 1 also indicated that the amount of CO_2 emission during the material period is higher than that during the manufacturing period. Furthermore, in order to evaluate the CO_2 emission during the transportation period, we chose two transportation routes from the location of the company cargo storage place to the location of Taijiang House, and compute the CO_2 emissions of the BIPV distribution by following data from the Bureau of Energy in Taiwan: 1. The 3.5 tons of container trucks with its average fuel consumption of 3.7km / L; 2. The per liter of diesel discharge 2.6kg- CO_2. [5, 6] Thus, the CO_2 emissions of the BIPV module during the transportation period are 96.05 kg- CO_2 (LINE A) and 112.55 kg- CO_2 (LINE B), respectively.

Table 1 BIPV specification and CO_2 emission during manufacturing period

Type	Photo	L (cm)	W (cm)	Weight (kg)	Solar cells	CO_2 emissions (kg-CO_{2e})		
						Materials	Manufacturing	Total
PM240P00		166.8	100	20	60 tablets / 15.6 x15. 6 (cm^2)	206.47	77.43	284.9
PM250M00		165.1	99.2	19.3	60 tablets / 15.6 x15. 6 (cm^2)	266.14	60.36	326.5

Table 2 The CO_2 emissions of BIPV during the transportation period

	Line	Distance (km)	CO_2 emissions (kg-CO_{2e})
			
	A	157	96.05
	B	184	112.55

ISBN: 978-84-697-1815-5

Table 3 lists the annual electrical power generation results for a whole year, with these being 9344.461 kWh for the south-facing roof. In addition, according to the information from Bureau of Energy in Taiwan, BIPV discharges 0. 085 kg- CO_2/kWh when it is operating, and The CO_2 emission factor used is 0.612kg- CO_2/kWh. [7, 8] Then, the amount of annual CO_2 emissions for different type's BIPV roofs can be estimated in Table 3.

In this study, the CO_2 emission evaluation during the using period, the lifetime of BIPV is assumed as 20 years, Thus, the CO_2 emissions of BIPV roof installed on the Taijiang House from the raw material conversion period to operating period are calculated in Table 4. Because the CO_2 emissions of Line A is lower than Line B, so we just use the data of the CO_2 emissions of Line A to describe the carbon footprint of BIPV roof (as shown in Imagen 6). The estimation results in Imagen 6 show that the BIPV roof could be a carbon minus a facility over 2.5 years.

Table 3 Annual CO_2 emissions and electricity generation of BIPV roof

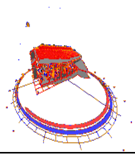
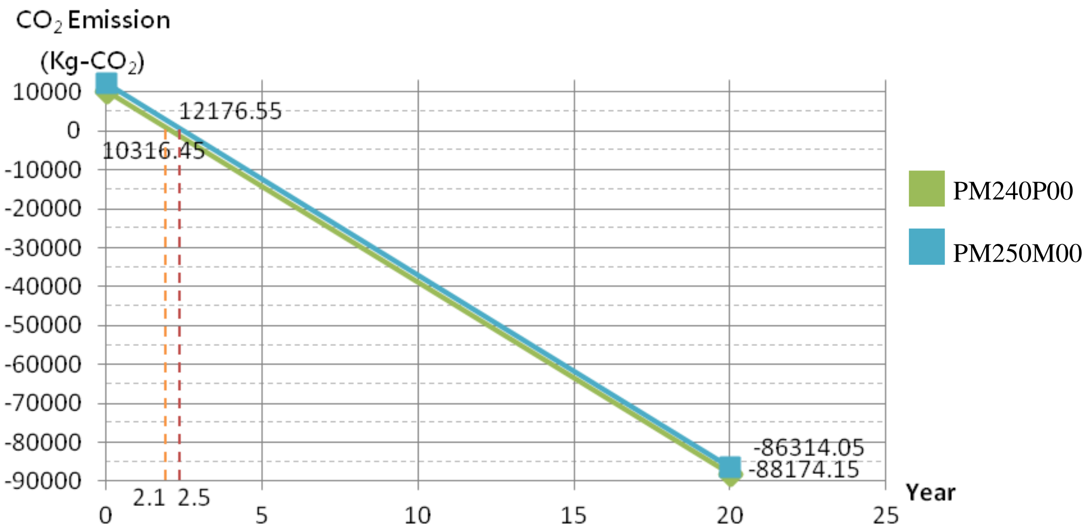
	BIPV Area (m^2)	Producing energy in a year (kWh)	CO_2 emissions in a year (kg-CO_{2e})	Reduction of CO_2 emissions in a year (kg-CO_{2e})
	61.026	9344.461	794.28	-5718.81

Table 4 Life cycle assessment of CO_2 emissions for BIPV roof installed on Taijiang House

Type	Amount of BIPV (piece)	CO_2 emissions (kg-CO_2)					Reduction of CO_2 emissions during 20 years using period (kg-CO_2)
		Materials	Manufacturing	Transportation		CO_2 emissions during 20 years using period	
				Line A	Line B		
PM240P00	36	7432.92	2787.48	96.05	112.55	15885.6	-114376.2
PM250M00	37	9847.18	2233.32				



ISBN: 978-84-697-1815-5

Imagen 6 The carbon footprint of BIPV during BIPV's the lifetime

CONCLUSIONS

The objective of this study is to evaluate the GHG emission of a BIPV roof applied in "Taijing Green Energy Building" (TGEB) by the LCCM method. Based on the evaluation results obtained, the following conclusions can be drawn up.

(1) Through a few investigations to the GHG emissions of PV module during material and the manufacturing period in this study, the GHG emission of two types of poly-crystalline PV module are 284.9 kg- CO_{2e} (PM240P00) and 326.5 kg- CO_{2e} (PM250M00) during material and manufacturing period, respectively.
(2) The PV panels installed on the roof of "Taijiang House" can generate 9344.46 kWh annual electricity power by using computer simulation.
(3) Based on LCCM method, the carbon payback period of PV roof is about 2.5 years. It in worth noting that the carbon payback period of PV roof is less than the cost payback period of PV.

REFERENCES

1. Ed, D., Pirter, T. (2014) Trends in Atmospheric Carbon Dioxide. NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/)

2. Terry, B., Igor B., Lenny B., Jean B., Peter B., Rutu D., Ogunlade D., Brian F.,Michael G., Sujata G., Kirsten H., BertJan H., Suzana Kahn R., Shigeki K., Mark L., Daniel M.,Omar Masera C., Bert M., Leo M., Gert-Jan N., Adil N., Nebojsa N., Hans Holger R., Joyashree R.,Jayant S., Robert S., Priyaradshi S., Ralph S., Pete S., Rob S., Dennis T., Diana U.-V., & Zhou D. (2007) Summary for Policymakers. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC Cambridge University Press, Cambridge, United Kingdom and New York, USA.

3. Chen Y. J., Zhang H., Lee S. K. (2014) Integration and Evaluation on Sensitive Living Environment and Green Energy Building in Taiwan. 2014 Regional Environmental Impact Assessment (EIA) Symposium, Hong Kong.

4. Takase K., Nakagawa A., Kuwasawa Y., Mae M., Murakami S. (2013) THE RESULT OF EXPERIMENTAL RESIDENCE IN LCCM DEMONSTRATION HOUSE. AIJ Journal of Technology and Design; ISSN: 1341-9463; VOL.19; NO.42; PAGE.661-664.

5. Environmental Protection Administration, Executive Yuan. (2008) The Research of the Agricultural Waste (Rice Straw) Collect Way and Its Cost, EPA-97-H103-02-141, Taipei, Taiwan.

ISBN: 978-84-697-1815-5

6. Tickell J. (1999) From the fryer to the fuel tank, 2nd Ed. Sarasota, FL: Green Teach Publishing.
7. Kangkang W. (2013) Assessment of photovoltaic application on a residential building, Department of Building, Energy and Environmental Engineering, University of Gävle, Sweden.
8. MOEA (2010). Emission Factors of Air Pollutant for Electricity Production. Bureau of Energy, Ministry of Economic Affair, Taiwan.