Building Integrated Photovoltaic Facades in Singapore: Online BIPV LCC Calculator

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***ABSTRACT* — In highly urbanized cities, the roof-top space available for solar photovoltaics (PV) may not be sufficient to make a major contribution to the renewable energy supply of the building. Adding BIPV to the façade is one possibility, however apart from architectural considerations, it is a pre-requisite to address the techno-economic aspects of BIPV facades over the life cycle of the building. This paper discussed the real world test bedding of BIPV façade at the National University Singapore (NUS) campus. Based on the results from the technical assessment of BIPV test-bed, combined with assumptions from commercially available PV technologies and façade installation cost, an online BIPV Life Cycle Cost Calculator was developed for the assessment of the feasibility of BIPV facades and available online at the National Solar Repository of Singapore (NSR) website.**

I. INTRODUCTION

Buildings, both residential and commercial, are responsible for more than one third of the global energy consumption. In particular, building sector in Singapore accounts for 38 percent of total energy consumption. Besides energy efficiency measures, the need for CO_2 reduction and net-zero energy buildings, the city's electricity demand has to come from renewable sources of energy by incorporating novel solar technologies in building applications. Innovative trend to harvest the clean energy and reduce the greenhouse gas emissions is to replace conventional materials in the building envelope with building integrated photovoltaics (BIPV) as a function of the advanced building skin.

This is a turning point in achieving the Net-Zero-Energy Buildings not only by on-site energy generation but also, through reduction of solar heat gain into the building (thus reducing cooling loads) and can assist in thermal comfort enhancement. BIPV technologies available in the market provide large diversity of technologies for architectural integration in form of colors (white, black, gold, silver, blue, green, etc), transparencies (10-90%), shapes, and patterns. BIPV systems must not only fulfil the requirement of the building envelope for water tightness, reliability, heat protection, etc., but also comply with local building codes and regulations. In addition, economic viability of BIPV technologies is still necessary to overcome BIPV barriers and make BIPV implementation more cost-effective.

This paper discussed the real world test bedding of three commercially available BIPV technologies as double-skin façade in front of the existing windows of a conference room at the School of Design and Environment (SDE) on the National University of Singapore (NUS) campus. Based on the results of BIPV test-bed, combined with assumptions from commercially available PV technologies and façade installation cost, an online BIPV Life Cycle Cost (LCC) Calculator was developed. This BIPV LCC calculator is a simplified assessment tool that should enable architects, engineers and building-related professionals to make a decision about implementation of BIPV into the façades during early design stage.

II. EXPERIMENAL SET-UP

Three commercially available BIPV technologies, namely, i) semi-transparent PV module with mono-crystalline silicon cells, ii) colored PV module with mono-crystalline silicon cells, and iii) opaque PV module with multi-crystalline silicon cells were subsequently installed and measured in tropical environment with high-precision equipment at the National University of Singapore Campus. Aim of BIPV test-bed was to assess BIPV technologies regarding their electrical performance under two different installation conditions: with and without passive cooling through ventilation of the double-skin façade, see Figure 1.

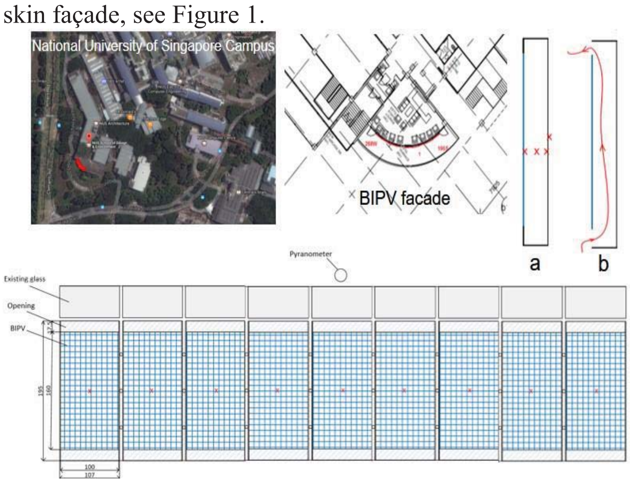

Figure 1. Location and technical details of the a – non-ventilated BIPV façade, and b- ventilated BIPV facade at the School of Design and Environment, NUS.

In addition, the architectural integration and aesthetic of BIPV façade has been assessed by integrating of multifunctional colored, semi-transparent and black PV technologies see Figure 2.

Figure 2. Architectural integration of various BIPV technologies.

III. Online BIPV LCC Calculator

Economic aspects for three different types of BIPV has been investigated by comprising the cost of commercially available BIPV technologies, system capacity, operating and maintenance costs, financial assumptions, energy efficiency and CO2 savings (including carbon tax savings) into the online assessment tool – BIPV LCC Calculator.

Assessment of BIPV system comprises three steps. First step is to input the initial available area and orientation of the building, i. e South, North, East and West façade, see Figure 3.

Figure 3. Initial inputs for available BIPV installation are and orientation of the building façade.

Second step is to specify possible details: discount rate, area factor of PV module per m^2, system price, cost of operating and maintenance for the façade, annual reserve for inverted replacement, inflation rate, and system lifetime. Performance ratio, system degradation rate, energy efficiency benefits (inm the form of solar heat gain coefficient or cooling load reduction), electricity price (SGDcent/.kWh) and electricity grid emission factor if any, see Figure 4.

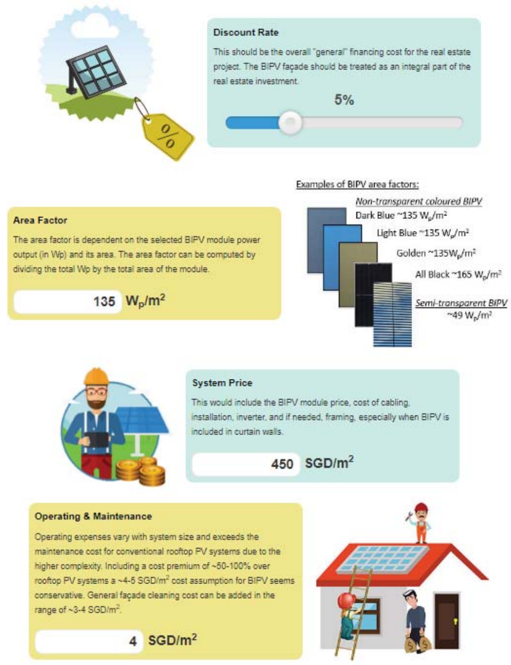

Figure 4. Details of the BIPV system, economics and efficiency factors in online toolkit.

Step 3 is to review the results, see Figure 5 and 6. Results window provide two comprehensive interpretations: i) Life Cycle Cost and ii) Environmental Benefits.

Life cycle cost include the detailed breakdown of initial investment, operating and maintenance, inverted warranty reserve, electricity generation, additional energy benefits, and final life cycle cost over the life cycle of the building, in Singapore is around 30 years. On the left side from the LCC graph the additional outputs of the model is highlighted, such as total BIPV area in m^2, total investments and life cycle cost per m^2.

Environmental benefits represent the PV system contribution to the environment in form of green electricity production over the system's lifetime in (kWh). In addition, results indicates the amount of avoided CO_2 over the life cycle of the BIPV system. For better understanding of value of green electricity LCC Calculator includes few indicators of how many airconditioners for one year or how many days of all mobile phone charging in Singapore can be powered up with green electricity from particular BIPV system.

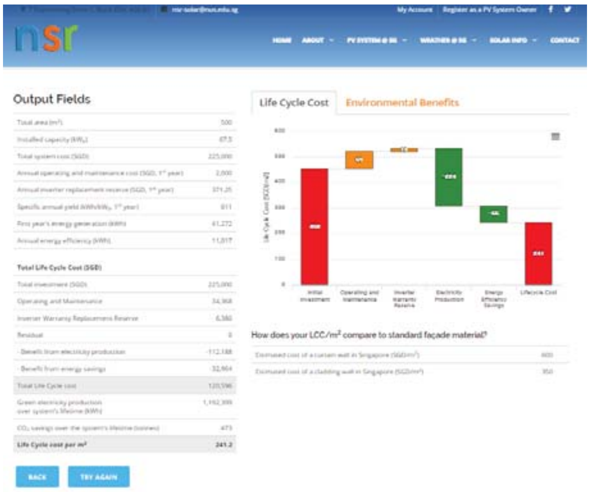

Figure 5. Results of BIPV LCC Calculator: Life Cycle Cost

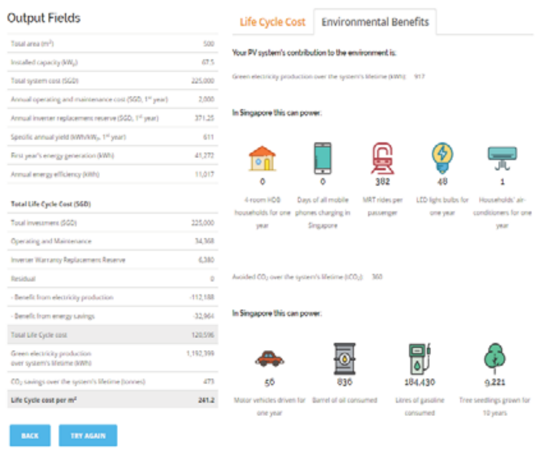

Figure 5. Results of BIPV LCC Calculator: Environmental Benefits

III. Conclusion

Based on the results from the technical assessment of BIPV façade test-bedding at National University of Singapore Campus, combined with assumptions from commercially available BIPV technologies and façade installation cost, an online "BIPV Life Cycle Cost" toolkit was developed for the assessment of the feasibility of BIPV facades.

The toolkit is suitable for architects, developers and building owners to obtain a comprehensive life cycle cost analysis of BIPV placement for various orientation and applications in buildings for further decision making. This includes the total investment requirements, and a detailed breakdown of the benefits of BIPV integration, i.e. energy savings, CO_2 emission avoidance and payback period.

The BIPV Life Cycle Cost toolkit for tropical environments is available online at the National Solar Repository of Singapore website [1].

Acknowledgement

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References

[1] National Solar Repository of Singapore. Available at http://www.solar-repository.sg.