Economics of building-integrated solar thermal systems

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This paper presents a general methodology to evaluate the economic benefits of building-integrated solar thermal systems (BIST). It defines cost categories, which are useful to compare variants of building envelopes on different levels of detail. Additionally, five general challenges for accurate economic evaluation of BISTS are presented including a discussion on recommendations.

1. Introduction to BISTS economics

The economic benefit of BISTS (like BIPV) can be identified based on the direct economic impact, indirect economic impact, and qualitative value as outlined below.

1.1. Direct Economic Impact

Any integrated building solar system is generally procured through a construction budget. Any thermal energy offset by the BISTS generates a saving that can reduce the building's operational cost. The BIST system also reduces the overall construction material costs (opposed to separate elements) (figure 1) and may offer additional revenue in the form of financial incentives and tax credits. In the in case of Hybrid PVT building integrated systems there is also a reduction in electricity costs, perhaps improving power yield (due to lower module temperatures) and reliability.

Figure 1: Combined BIPV and BIST roofing systems that offset traditional roofing material costs

1.2. Indirect Economic Impact

Many businesses and organisations may have a 'worth' attributed to company goals or interests, being sustainable or 'green' is one obvious example. Offsetting fossil fuel usage through a BISTS may equate to environmental emission reductions, which if they can be quantified, valued or perhaps even traded will accrue additional economic benefits. A further indirect cost may be achieved through the BIST system's contribution to a building's thermal performance. Through improved envelope structures reduced heat loss or heat gain can have a

positive impact on auxiliary thermal or air conditioning loads. Likewise, BISTS that offer a shading function (without reducing daylight penetration) can have further cost benefits.

1.3. Qualitative Value

Some BISTS benefits are subjective. For some building operators, a considerable value of a BISTS may be associated with a positive image, public awareness (figure 2) and perception or impact on the built environment (LCA or embodied energy) when the technology is installed. It is very difficult to assign a true cost value to these subjective considerations, but they do influence the value of the BIST system installed and how the building operator views them.

Figure 2: Façade mounted BIST designed to emphasis its existence to ensure public awareness © CitrinSolar GmbH

Given the many variables and economic impacts, to physically quantify the value of any BIST system is a complex task. The following section sets out a general methodology, followed by a discussion of the challenges faced when applying the method.

2. General methodology

To determine to actual cost of a BISTS, a number of initial cost estimates must be considered; investment cost and economic savings. This section is based on (Maurer et al., submitted).

2.1. Investment Cost

The BISTS investment cost is estimated per square meter from the additional costs associated by the solar thermal element added to the building envelope (c_{idsenv}). This can be calculated as the difference between the overall investment cost per square meter of the BISTS building envelope (c_{isenv}) and the investment cost per square meter related to a conventional element of the building envelope (c_{irenv}) as the reference

$$c_{idsenv} = c_{isenv} - c_{irenv} \qquad [1]$$

The first challenge is to define the reference building envelope as there are many reference possibilities available, although just one needs to be derived for the first approximation. The same approximation process needs to be conducted for the building services element and their respective interconnection. The investment cost for the building services includes the solar thermal function per square meter of BISTS area (c_{idbs})

$$c_{idbs} = (c_{isbs} - c_{irbs}) / A_{BISTS} \qquad [2]$$

Where (c_{isbs}) is the investment cost for the building services in a BISTS configuration and (c_{irbs}) is the investment cost for the building services based on the reference case (c_{irbs}) and (A_{BISTS}) is the effective surface area covered by the BISTS.

If the value of a building including BISTS can be estimated reasonably well without the financial savings by the BISTS and reflecting only the image of the BISTS building, then the difference between the value of a BIST building $c_{iBISTbuild}$ and its reference building $c_{irbuild}$ can also be considered

$$c_{idBISTbuild} = (c_{iBISTbuild} - c_{irbuild}) / A_{BISTS} \quad [3]$$

The total investment cost (c_{dBISTS}) for the solar thermal element of the building envelope, including the necessary building services is calculated by

$$c_{idBISTS} = c_{idsenv} + c_{idbs} - c_{idBISTbuild} \quad [4]$$

In addition, the annual operating costs per square meter for the BISTS, maintenance (c_a), the discount rate (r) and the service life of the system (T), must be estimated.

2.2. Potential Economic Savings

In order to determine the potential economic savings, the performance of the BISTS needs to be estimated. The calculation methods used in the economic assessment of conventional solar thermal collectors may be used (in general terms) if the building integration element is neglected. Otherwise, a better approximation may be arrived at by using a simple model for BISTS (Maurer et al., 2015) or a detailed physical model if it is available (Lamnatou et al., 2015b, 2015a). The solar thermal performance of the BISTS can only be applied to a specific climate at a specific physical mounting and orientation and needs to be calculated to include the building and building services load for both with and without the BISTS installed. The result of such a simplified approach yields the typical annual non-renewable primary energy demand for the BISTS (Q_{BISTS}) and the typical annual non-renewable primary energy demand for the reference case (Q_r), both in terms of kWh/a.

These values can then be used to determine the non-renewable primary energy saving (Q_{dBISTS}) by the BISTS in one year for the specific location dependant applications and per square meter of BISTS area (q_{dBISTS})

$$q_{dBISTS} = (Q_r - Q_{BISTS}) / A_{BISTS} \quad [5]$$

The cost of saved non-renewable primary energy energy (c_{sh}) is calculated by

$$c_{sh} = \frac{c_{idBISTS} + \sum_{n=1}^{T} c_a (1+r)^{-n}}{\sum_{n=1}^{T} q_{dBISTS} (1+r)^{-n}} \quad [6]$$

This is the sum of the total cost of ownership per square meter of BISTS divided by the total savings of non-renewable primary energy both at present time. In a European context this can be regarded as the Levelized Cost of Heat (LCoH) in €/kWh, with the caveat that it includes not only the contribution of renewable heat of the solar thermal element but also includes the

influence of the BISTS on the building heating and cooling demand. A negative cost value represents a profit.

The cost of saved non-renewable primary energy (c_{sav}) can be compared with the LCoH of non-renewable heat sources. Together with an average CO_2 emission per kWh of non-renewable primary energy (e), the cost of saved CO_2 emissions (c_{sc}) can be calculated

$$c_{sc} = \frac{c_{sh}}{e} \qquad [7]$$

3. Challenges in BISTS application

There are numerous challenges that exist for any renewable and non-renewable investments; however the challenges are exceptionally large for new and emerging areas in building integrated solar with particular issues for innovative BIST systems. Many stakeholders do not have significant experience of BISTS and minimal information is available surrounding BISTS (when contrasted to BIPV) and virtually nothing relating to the detailed economic performance of BISTS. Figure 3 demonstrates a simpler option; using proprietary collectors and 'off the shelf' components to lessen the unknown challenges.

Figure 3: Proprietary evacuated tube array installed in BIST format

3.1. The challenge of influence

It is difficult to quantify the value of a BISTS solution in general, because the performance of a BISTS is very dependent upon the location, orientation, building configuration and its respective building services infrastructure. Specific cases can be analysed and optimised, but if only one parameter is changed, the performance and associated economics of the whole system can be significantly altered. To address this issue, 'reference installations' are analysed in detail to identify which parameters (or range of parameters) can be used as indicators in benchmarking performance.

3.2. The challenge of detail

At the outset of any building construction exercise, important detailed design consideration is minimal. These design decisions are crucial to the effective simulation of BISTS performance and yet often the time and effort required through detailed modelling and simulation of the BIST envelope cannot be justified. Generating a large (open access) database relating to BISTS characteristics and features, together with performance calculations and measurements

and associated economic and cost values could help prospective BISTS stakeholders to make initial (ball-park) estimations for their specific BISTS projects.

3.3. The challenge of quantifying

The value of a building depends on many factors one of which is thermal performance. Whilst information relating to building performance through a building envelope thermal resistance or the time since the last building envelope refurbishment is important, there are many subjective parameters that are just as important in how a building is valued. The aesthetics of a building are very important and the inclusion of a BISTS could have a significant impact of the appearance of the building envelope. Aesthetics and other opinion based factors, unlike a thermal characteristic, are very hard to quantify. Stakeholders can estimate the particular benefits and drawbacks based on their experience and/or on feedback from targeted surveys in which they can ask opinions on differing building envelope configurations. Information relating to wide scale statistical surveys on such parameters on existing buildings with or without BISTS would be beneficial to potential stakeholders.

3.4. The challenge of differences

When deciding upon a perfect reference BISTS envelope, it is obvious that no one function can be considered in isolation and therefore selecting a system based on solar contribution alone without considering a different appearance or mounting configuration, for example is difficult. One factor will always influence another and this difference in like-for-like comparison will always influence the consumer's choice of system. BISTS envelopes compete with many other building envelope possibilities and often consideration of investment cost, ecological or architectural/aesthetic factors may often be more important that the inclusion of a renewable energy system in the building fabric. The wide variety of options is in its own a significant barrier to choice and may only be addressed by analysing a select few of the most promising examples. Similarly, changes to the BISTS envelope can have a negligible or significant impact upon the demand on building services systems, adding a further additional challenge. One BISTS configuration may reduce the cooling load passively (reducing AC loads) whilst another system provides a (renewable) heat supply to the building but uses additional electricity. These differences make the energy cost and associated CO_2 emissions more difficult to compare than in a case where just one variable changes. Such issues can be analysed in detail, but often need specific expertise to be accurately assessed.

3.5. The challenge of the future

No one knows exactly how the BISTS technologies of today and associated economics will evolve in the future, which in turn implies that a lot of assumptions regarding energy prices and discount rates, for example, will be necessary. Likewise for new and untried products, the required maintenance or service life can be estimated, but some uncertainty will always remain. To quantify the uncertainty in BISTS, the following procedure is recommended which is based on the Monte-Carlo method. Firstly, the important output values and the most uncertain parameters are defined and the uncertainty of these parameters is estimated. Then a large number of random parameter groups are generated based on the uncertainty of the individual parameters. Finally the output values are calculated for each parameter set and are presented in histograms. By analysing these histograms the risk of deviations within a certain range can be quantified.

4. Conclusions

This paper outlines forms of economic impact and value associated with BISTS and presents a generalised methodology for calculating BISTS economic investment potential. Several

important challenges have been recognised, highlighting the difficulties that may arise in using such a generalised approach. Finally, appropriate solutions have been suggested that address the limitations and knowledge gaps that currently exist in resolving the future challenges identified. For the first time, a simple framework has been created that forms the basis for an applied economic analysis of existing and new BISTS.

5. Acknowledgments

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6. References

Lamnatou, C., Mondol, J.D., Chemisana, D., Maurer, C., 2015a. Modelling and simulation of Building-Integrated solar thermal systems: behaviour of the coupled building/system configuration. Renewable and Sustainable Energy Reviews 48, 178–191.

Lamnatou, C., Mondol, J.D., Chemisana, D., Maurer, C., 2015b. Modelling and simulation of Building-Integrated solar thermal systems: Behaviour of the system. Renewable and Sustainable Energy Reviews 45, 36–51.

Maurer, C., Cappel, C., Kuhn, T.E., submitted. Progress in building-integrated solar thermal systems, in: Elsevier (Ed.), Progress in Solar Energy.

Maurer, C., Cappel, C., Kuhn, T.E., 2015. Simple models for building-integrated solar thermal systems. Energy and Buildings 103, 118–123.