# Exergoeconomic Assessment of a Building Integrated Photovoltaic (BIPV) System: A Case Study of Yasar University, Izmir, Turkey


**Arif Hepbasli (Presenter)**
**Emrah Biyik**
**Mustafa Araz**
Yasar University, Turkey

**Running Yao**
**Mehdi Shahrestani**
**Emmanuel Essah**
**Li Shao**
The University of Reading, United Kingdom

**Armando C. Oliveira**
University of Porto, Portugal

**Teodosio del Caño**
**Elena Rico**
**Juan Luis Lechón**
Onyx Solar Energy S.L., Spain


**(ID: 5689)**


**World Sustainable Built Environment Conference 2017 Hong Kong**
Transforming Our Built Environment through Innovation and Integration: Putting Ideas into Action, 5-7 June 2017

About WSBE17 Hong Kong | Programme | Call For Papers | Registration | Exhibition & Sponsorship | Hong Kong Report | General Information | Media

# MAIN CONFERENCE

Conference Day 2
**6 June 2017**

## 16:30-18:00 Parallel Session 4

**Session 4.3: Advanced Building Systems – Energy Generation (2)**

Exergoeconomic Assessment of a Building Integrated Photovoltaic (BIPV) System: A Case Study of Yasar University, Izmir, Turkey

Arif HEPBASLI
*Chairman of Energy Systems Engineering Department, Yasar University, Turkey*

# Outline

- 1. REELCOOP Project, funded, EU-FP7
- 2. Literature Review
- 3. System Description
- 4. Analysis
- 5. Results
- 6. Conclusions

# 1. REELCOOP Project, funded, EU-FP7

# REELCOOP

*REnewable ELectricity COOPeration*

*EU-FP7 project under the Energy 2013 call*

Starting date : 01/09/2013
Duration : 4 years
(excl. an extension of 6 months)

# REELCOOP-Partners (http://www.reelcoop.com/)

**research institutions:**

U.PORTO

University of Reading

UNIVERSIDADE DE ÉVORA

DLR

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

IRESEN

YASAR UNIVERSITY

CDER

**companies:**

onyx

MCG mind for metal

TermOcycle

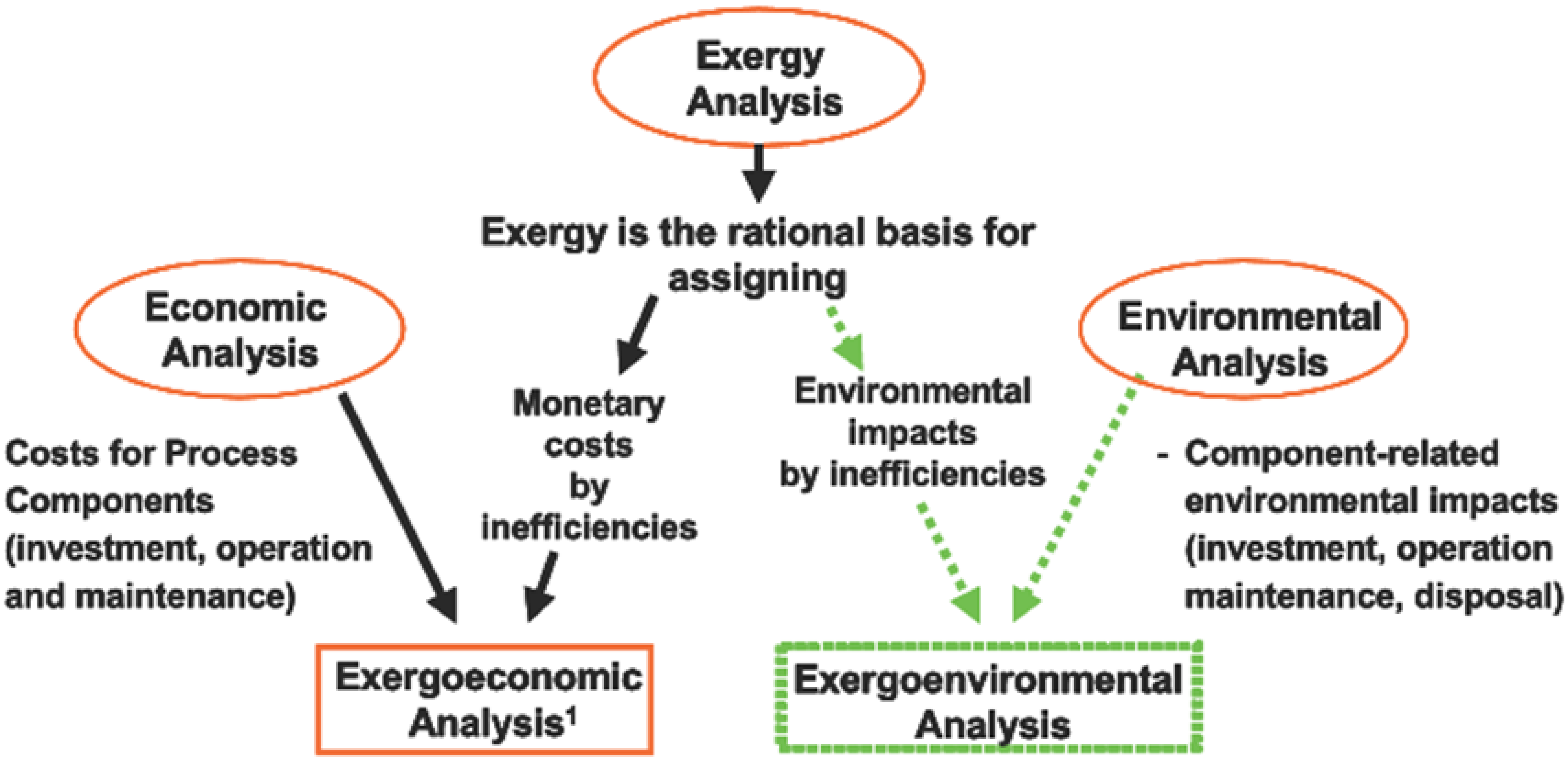
soltigua

ZUCCATO ENERGIA

AES

## 15 Partners from 10 Various Countries

# 2. Literature Review




**Analogy between Exergoeconomic and Exergoenvironmental Analysis**

[1]Source: Bejan, A., Tsatsaronis, G., Moran, M., 1996, Thermal Design and Optimization. New York: John Wiley.

# Various Exergoeconomic (in Europe) or Thermoeconomic (in the U.S.) Approaches

Classified into the three fields: cost allocation, cost optimization, and cost analysis.

- Exergy Economics Approach (EEA) [1]
- First Exergoeconomic Approach (FEA) [1]
- Thermoeconomic Functional Analysis (TFA) [1]
- Exergetic Cost Theory (ECT) [1]
- Engineering Functional Analysis (EFA) [1]
- Last-In-First-Out Approach (LIFOA) [1]
- Structural Analysis Approach (SAA) [1]
- Specific Exergy Costing (SPECO) Method (SPECOM) [1]
- **………Exergy, Cost, Energy and Mass (EXCEM) [2] (Present Study)……….**
- Modified EXCEM [3]
- CGAM Method (derived from the initials of a group of concerned specialists, namely C. Frangopoulos, G. Tsatsaronis, A. Valero, and M. von Spakovsky) [4]

**Sources:**


[1] Meyer et. al. Application of Exergoeconomic and Exergoenvironmental Analysis to an SOFC System with an Allothermal Biomass Gasifier. Int. J. of Thermodynamics 12 (4): 177-186 (2009).

[2] Rosen MA, Scott DS. A methodology based on exergy, cost, energy and mass for the analysis of systems and processes. In: Proceedings of the meeting of nternational society for general systems research, Vol. 8.3, Toronto, 20–22 May; 1987. p. 1–13.

[3] Gaur, A, Tiwari, GN. Exergoeconomic and enviroeconomic analysis of photovoltaic modules of different solar cells. Journal of Solar Energy. Hindawi Publishing Corporation. Volume 2014, Article ID 719424, 8 pages, http://dx.doi.org/10.1155/2014/719424

[4] Kim, D.J. A new thermoeconomic methodology for energy systems. Energy 35(1):410-422 (2010).

Engineering Science and Technology, an International Journal xxx (2017) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: www.elsevier.com/locate/jestch

Review

# A key review of building integrated photovoltaic (BIPV) systems

Emrah Biyik[a], Mustafa Araz[a], Arif Hepbasli[a,*], Mehdi Shahrestani[b], Runming Yao[b], Li Shao[b], Emmanuel Essah[b], Armando C. Oliveira[c], Teodosio del Caño[d], Elena Rico[d], Juan Luis Lechón[d], Luisa Andrade[e], Adélio Mendes[e], Yusuf Baver Atlı[f]

[a] Department of Energy Systems Engineering, Faculty of Engineering, Yasar University, 35100 Bornova, Izmir, Turkey
[b] School of Construction Management and Engineering, The University of Reading, Whiteknights, PO Box 219, Reading, Berkshire RG6 6AW, United Kingdom
[c] Mechanical Engineering Department – FEUP, University of Porto, 4200-465 Porto, Portugal
[d] Onyx Solar, C/ Rio Cea 1-46, 05004 Ávila, Spain
[e] LEPABE – Faculdade de Engenharia, Universidade do Porto, rua Dr. Roberto Frias, 4200-465 Porto, Portugal
[f] Graduate School of Natural and Applied Sciences, Ege University, 35100 Bornova, Izmir, Turkey

| Peformance Assessment | | | |
|---|---|---|---|
| Energy | Exergy | Economic | Environmental |

Table 1

## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jestch.2017.01.009

Solar Energy 147 (2017) 37–51

ELSEVIER

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

# Experimental and numerical studies to assess the energy performance of naturally ventilated PV façade systems

CrossMark

Mehdi Shahrestani[a], Runming Yao[a,*], Emmanuel Essah[a], Li Shao[a], Armando C. Oliveira[b], Arif Hepbasli[c], Emrah Biyik[c], Teodosio del Caño[d], Elena Rico[d], Juan Luis Lechón[d]

[a] School of the Built Environment, University of Reading, Whiteknights, PO Box 219, Reading RG6 6AW, United Kingdom
[b] Centre for Renewable Energy Research, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal
[c] Department of Energy Systems Engineering, Faculty of Engineering, Yasar University, 35100 Bornova, Izmir, Turkey
[d] Onyx Solar, C/ Rio Cea 1-46, 05004 Ávila, Spain

## Exergetic Analyses and Assessments (PV or PVT)

Joshi et al. (2008,2009): Studying on the performance characteristics of a PV and PV/T system based on energy and exergy efficiencies

Abid and Hepbasli (2012/2015): Assessing the exergetic performance of PV modules of a PV-wind hybrid system installed on the roof of Mechanical Engineering Department, King Saud University Riyadh, Saudi Arabia

Vats and Tiwari (2012): Performing energy and exergy analysis of a building integrated semitransparent photovoltaic thermal system

Saloux et al. (2013): Exergy analyses of PV/T or PV systems

Shukla et al. (2016): Reviewing some studies on exergetic assessment of BIPV modules

Hepbasli et al. (2016): Analyzing a BIPV system installed at Yasar University

# Exergoeconomic Analysis and Assessment (BIPV)

- Gaur and Tiwari (2014): Proposing the modified EXCEM method and calculating annual electricity and net present values for the composite climatic conditions of New Delhi, India.
- Hepbasli et al. (2016): Assessing the Performance of a BIPV system using the EXCEM method (The International Conference of SDB16, 5-6 November, Chongqing, China)
- Hepbasli et al. (2017): Evaluating the performance of a BIPV system through the SPECO method, IEEES-9, 15-17 May, Split, Croatia

- **Present Study**: Selected from SBE16 Chongqing for submission to WSBE17 and invited for presentation at WSBE17 Hong Kong as one of two "SBE16 Top Papers"

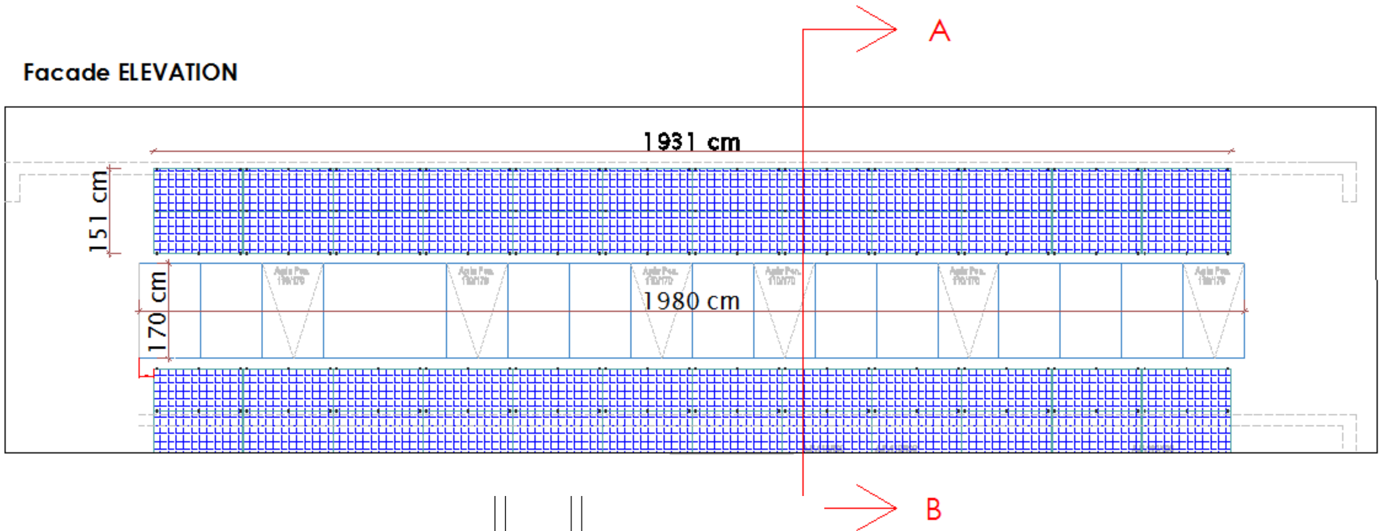
# 3.System Description

## Commissioned on February 8, 2016

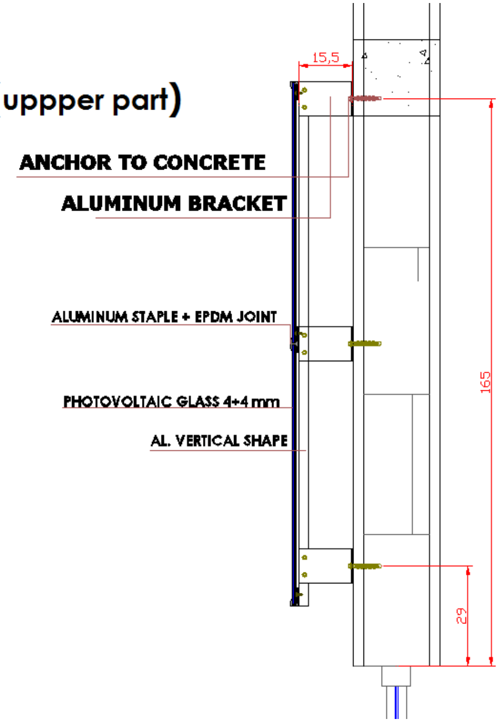
| | |
|---|---|
| Nominal Power | 155 Wp |
| $V_{oc}$ | 23 V |
| $I_{sc}$ | 8.62 A |
| $V_{nom}$ | 18 V |
| $I_{nom}$ | 8.40 A |
| Dimensions | 1600*750*8.5 mm |
| Area | 1.2 m$^2$ |
| Weight | 20 kg/m$^2$ |
| Cell type | 6“ mono-crystalline |
| Transparency | 30% |

- 48 panels
- 2 series
- 7.44 kWp (total)
- 150 mm air gap
- Total area: 57.6 m$^2$
- Cell area: 42.08 m$^2$

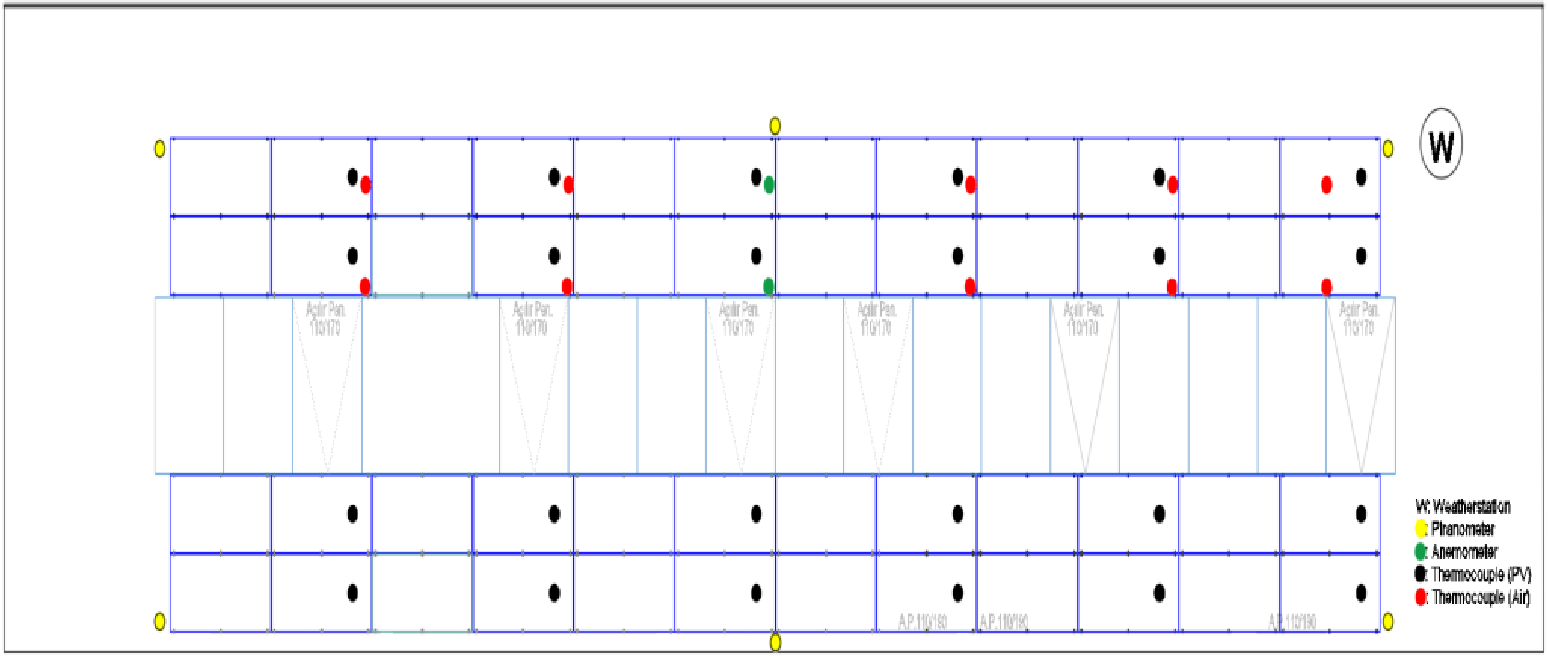
Facade ELEVATION



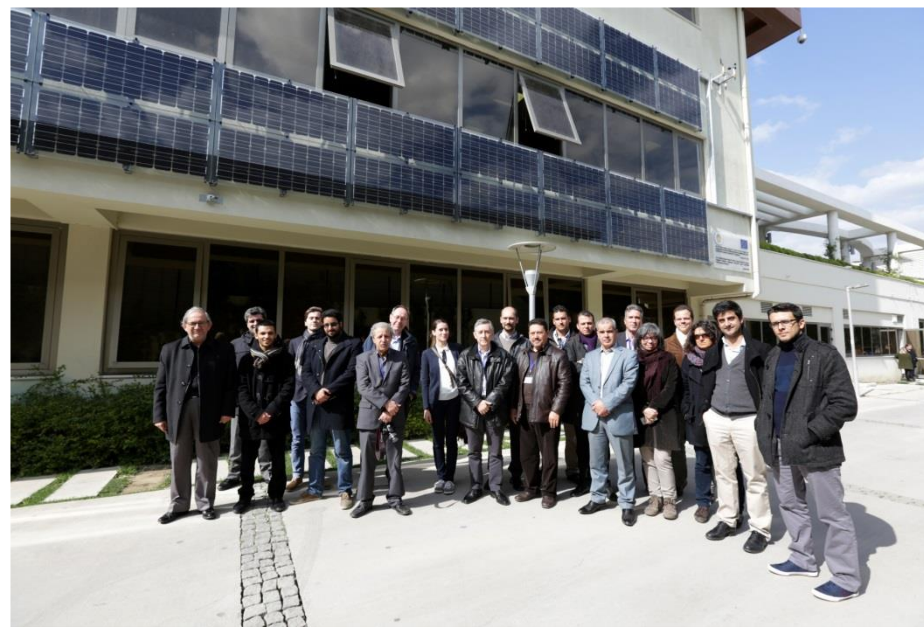

SECTION AB (uppper part)




- 48 mono-crystalline units
- 155 $W_p$/unit, dimensions
- 1650x850 mm
- Configuration 4+4 mm laminated tempered glass
- 15 cm between the wall and the PV facade




- Surface temperature at 24 points
- Air temperature at 12 points
- 6 pyranometers
- Air velocity
- Wind velocity-direction
- Outdoor air temp. and humidity



16 March 2016, Yasar University

# 4. Analysis

## Table 1. Relations used in exergy analysis [8,9,17,18,21-24]

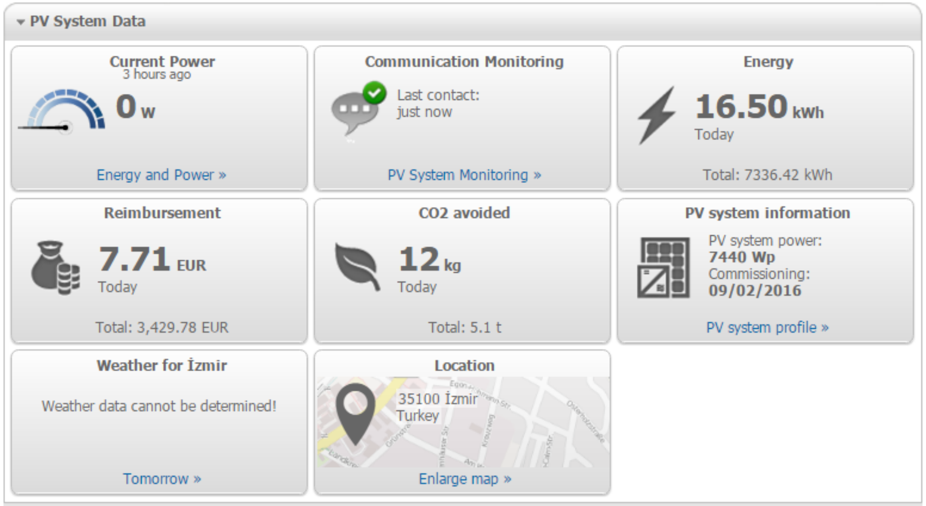
| Description | Relation | Remarks |
|---|---|---|
| Exergy efficiency of a PV system on the output/input basis | $\psi = \frac{\dot{E}x_{PV}}{\dot{E}x_{sol}}$ (5) | $\dot{E}x_{PV}$ : Exergy rate of the BIPV system |
| Exergy efficiency of a PV system | $\psi = \frac{V_{max} I_{max} - \dot{E}x_Q}{\dot{E}x_{sol}}$ (6) <br> $\dot{E}x_Q = \dot{Q}_{c,r}(1 - \frac{T_{amb}}{T_{mod}})$ (7) <br> $\dot{E}x_{sol} = GA\Psi_{ex,sol}$ (8) | $\dot{E}x_{sol}$ : Exergy rate from the solar irradiance (W/m$^2$) |
| Convective and radiative heat transfer coefficient from photovoltaic cell to ambient | $\dot{Q}_{c,r} = h_{ca} A(T_{mod} - T_{amb})$ (9) <br> $h_{ca} = 5.7 + 3.8V_{wind}$ (10) | $V_{wind}$ : Wind velocity (m/s) |
| Exergy of solar radiation (thermal radiation) [21-24] | $\Psi_{ex,sol,Petela} = 1 + \frac{1}{3}(\frac{T_0}{T_{sol}})^4 - \frac{4}{3}\frac{T_0}{T_{sol}}$ (11a) <br> $\Psi_{ex,sol,Spanner} = 1 - \frac{4}{3}\frac{T_0}{T_{sol}}$ (11b) <br> $\Psi_{ex,sol,Nobusawa} = 0.95$ (11c) <br> $\Psi_{ex,sol,Jeter} = 1 - \frac{T_0}{T_{sol}}$ (11d) | $T_{sol}$ : Solar radiation (sun) temperature with 6 000 K. |

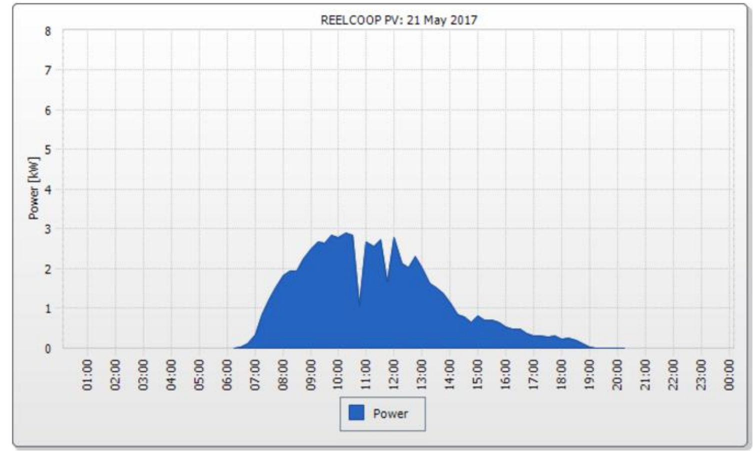
## Table 2. Relations used in exergoeconomic analysis [7,15,25]

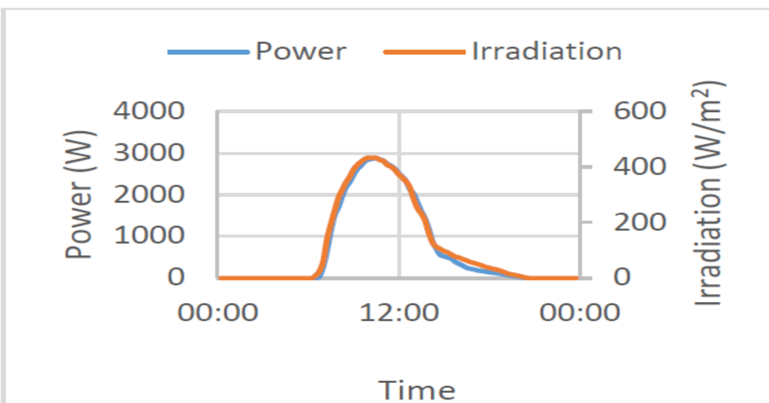
| Description | Relation | Remarks |
|---|---|---|
| Energy loss rate in general | $\dot{L}_{en} = \sum_{inputs}\dot{E} - \sum_{products}\dot{E}$ (13) | $\tau_{glass}$ : Transmitivity of the glass<br>$\alpha_{mod}$ : Absorption factor of the module<br>$\beta_{mod}$ : Packing factor |
| Exergy loss rate in general | $\dot{L}_{ex} = \sum_{inputs}\dot{E}x - \sum_{products}\dot{E}x$ (14) | |
| Energy loss rate for the BIPV system | $\dot{L}_{en} = \sum\tau_{glass}\alpha_{mod}\beta_{mod}G(t)A_{mod} - \sum\eta_{mod}G(t)A_{mod}$ (15) | |
| Exergy loss rate for the BIPV system [15] | $\dot{L}_{ex} = \sum\tau_{glass}\alpha_{mod}\beta_{mod}G(t)\Psi_{ex,sol,Petela}A_{mod} - \sum\eta_{mod}G(t)\Psi_{ex,sol,Petela}A_{mod}$ (16) | |
| Ratio of thermodynamic loss rate $\dot{L}$ to capital cost K | $\dot{R} = \dot{L}/K$ (17) | |
| Energy and exergy loss rates | $\dot{R}_{en} = \dot{L}_{en}/K$ (18) $\dot{R}_{ex} = \dot{L}_{ex}/K$ (19) | |

# 5. Results

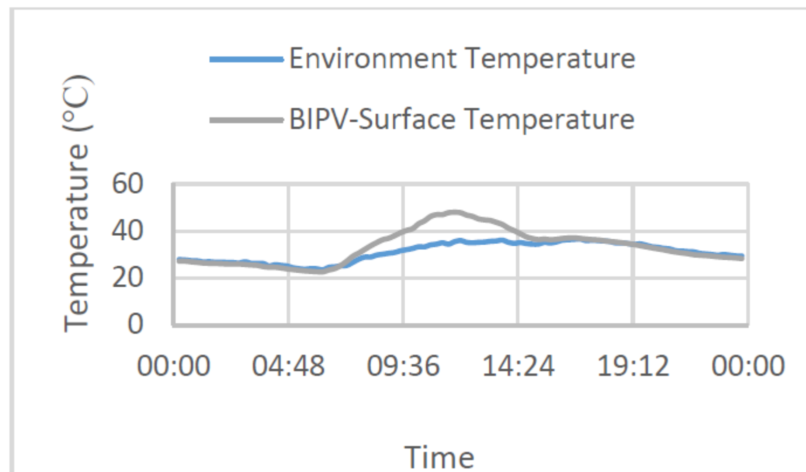
As of 21 May 2017: PV system power since its installation: **7337 kWp**



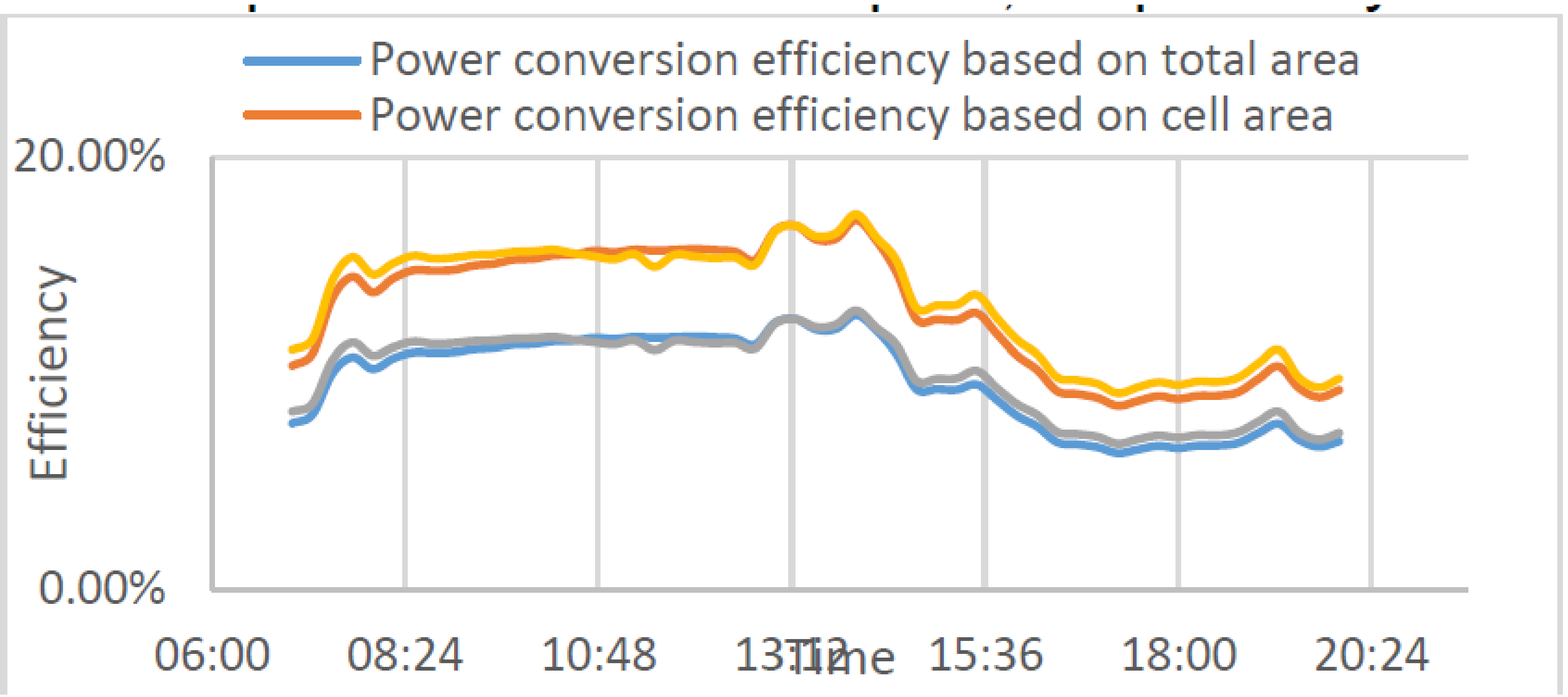



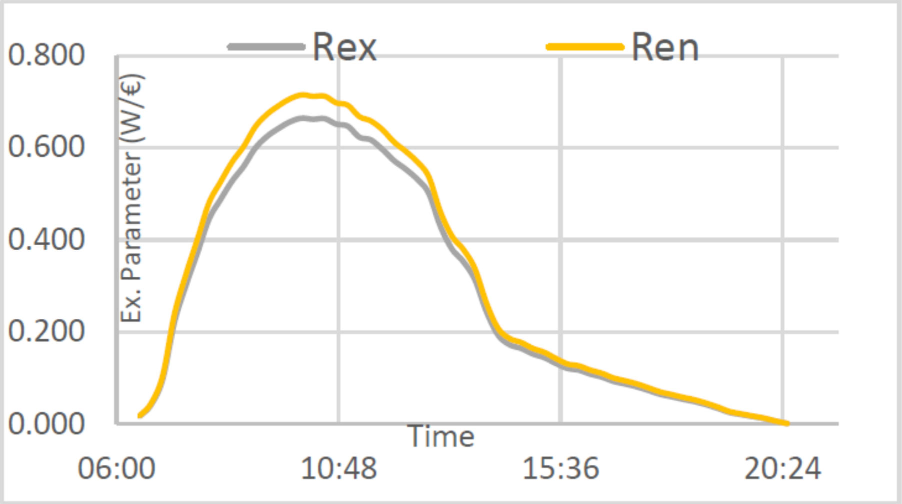

Daily power generation and irradiation distribution on July 23, 2016



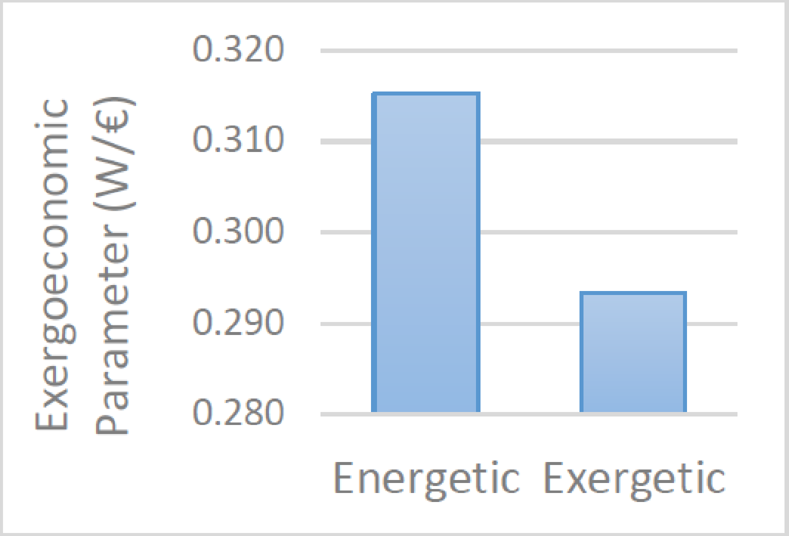

BIPV surface temperature vs. ambient temperature




Energy and exergy efficiency distributions




Daily variation of exergoeconomic parameter based on energy and exergy terms




Comparison of the daily averages of energy and exergy based exergoeconomic parameters

# 6. Conclusions

a) Exergy efficiency values are obtained to be in the range of about 7.3% to 12.9% and 9.8 to 17.4 based on total and cell areas over a daily period considered, respectively.

b) Exergoeconomic parameters based on the energetic terms are calculated to vary between 0.001 and 0.714 W/€ with a daily average of 0.315 W/€ while those based on the corresponding exergetic terms are in the range of 0.001 to 0.664 W/€, with a daily average of 0.293 W/€.

c) The authors expect that this study would be beneficial to the researchers, designers and manufacturers, who are interested in applying exergy-based economic analysis methods to BIPV systems.

# Acknowledgements

The presented work was developed within the framework of project "**REELCOOP** - Research Cooperation in Renewable Energy Technologies for Electricity Generation", co-funded by the European Commission (FP7 ENERGY.2013.2.9.1, Grant agreement no: 608466).