Solar Energy Materials & Solar Cells 156 (2016) 92–100

Contents lists available at ScienceDirect

Solar Energy Materials & Solar Cells

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

Solar heating and cooling systems versus conventional systems assisted by photovoltaic: Application of a simplified LCA tool

Marco Beccali, Maurizio Cellura, Sonia Longo*, Francesco Guarino

Dipartimento di Energia, Ingegneria dell'Informazione e Modelli Matematici – Università degli Studi di Palermo, Viale delle Scienze Ed. 9, 90128 Palermo, Italy

ARTICLE INFO

Article history:
Received 1 December 2015
Received in revised form
8 March 2016
Accepted 22 March 2016
Available online 5 April 2016

Keywords:
LCA
Solar heating and cooling
Photovoltaic
Primary energy
Greenhouse gas emissions

ABSTRACT

Life Cycle Assessment (LCA) is an effective methodology to assess the energy and environmental impacts of energy systems during their life cycle, including manufacturing, operation and end-of-life.

The aim of the paper is the application of a simplified LCA tool, developed in the framework of the International Energy Agency Solar Heating and Cooling Task 48, for comparing different typologies of solar assisted heating and cooling systems.

In detail, solar thermal heating and cooling systems located in Palermo (southern Italy) and in Zurich (Switzerland) were compared with conventional systems assisted by grid connected and stand-alone photovoltaic plants.

A validation of the tool was also carried out by comparing the obtained results with those of in-depth LCA studies.

The results showed that the best system configuration in Palermo is the conventional system assisted by a grid-connected photovoltaic plant. Its impact on global energy requirement is about 83.7% and 74.5% of the corresponding impact of the solar thermal heating and cooling and the conventional system assisted by a stand-alone photovoltaic system, respectively.

Different considerations can be made for Zurich, where the solar heating and cooling system performs better than the others; it is characterized by a global energy requirement that is 85.3% and 81.2% of the grid-connected and stand-alone photovoltaic assisted conventional systems, respectively. A similar trend is traceable for the global warming potential indicator.

The validation of the LCA tool proved it to be reliable since deviations with a detailed LCA of the same system are contained below a 5% difference in all the comparable systems.

1. Introduction

The current trend in the development of buildings, heating ventilation and air-conditioning systems points towards a growing integration between energy generation and consumption [1]. Renewable energy technologies (RETs) are an effective solution for matching the energy consumption over one year [2] and for achieving the target of nearly Net Zero Energy Buildings (NZEBs), as recommended by the European Energy Directive on Performance of Buildings [3].

Designing NZEBs [4–6] is, however, challenging. Since, by definition, the design of such buildings is interdisciplinary, design tools need to couple different domain models, in order to represent the interactions and conflicts that occur between problem parts and give rise to the need performance trade-offs [7]. Thus, it is important to develop new tools for the early design phase and/or to integrate new tools within the existing ones, to help practitioners and researchers taking in consideration the highest number of variable to be included in the design.

One aspect often overlooked is the embodied energy and greenhouse gas (GHG) emissions of the envelope and energy systems of NZEBs; the idea is that even though energy requirements during the use phase are zero and the net zero energy target is achieved, the environmental and energy impacts arising from the production and end-of-life might nullify the benefits of the use phase.

The analysis of embodied energy and GHG emissions in the early design phase is particularly important, since the design of NZEBs would always be characterized by very low use phase impacts in comparison to the other steps of the life cycle [8–13], and achieving a balanced and overall low life cycle impact design is one of the top priorities in current NZEBs research.

Among the energy systems that can be integrated in NZEBs, solar heating and cooling (SHC) systems as well as photovoltaic

* Corresponding author. Tel.: +39 091 23861927; fax: +39 091 484425.
E-mail address: sonialongo@dream.unipa.it (S. Longo).

http://dx.doi.org/10.1016/j.solmat.2016.03.025
0927-0248/

Nomenclature

Acronyms

EPT energy payback time
ERR energy return ratio
GER global energy requirement
GHG greenhouse gas
GWP global warming potential
GWP-PT global warming potential payback time
LCA Life Cycle Assessment
NZEB Net Zero Energy Buildings
PV photovoltaic

RETr renewable energy technology

SHC solar heating and cooling

Symbols

$GER_{Conventional\text{-}system}$ primary energy consumed by the conventional system during the manufacturing and end-of-life steps
$GER_{Conventional\text{-}system\text{-}operation}$ primary energy consumed by the conventional system during the operation step
$GER_{SHC\text{-}system}$ primary energy consumed by the SHC system during the manufacturing and end-of-life steps
$GER_{SHC\text{-}system\text{-}operation}$ primary energy consumed by the SHC system during the operation step
$GWP_{Conventional\text{-}system}$ impact on GWP generated by the conventional system during the manufacturing and end-of-life steps
GWP_{year} net yearly avoided GWP due to the use of the SHC system
$GWP_{SHC\text{-}system}$ impact on GWP generated by the SHC system during the manufacturing and end-of-life steps
$E_{overall}$ net yearly primary energy saving during the overall lifetime of SHC system
E_{year} net yearly primary energy saving due to the use of SHC system

(PV) systems are competitive technologies used to generate energy inputs, which can contribute to the reduction of buildings energy consumption and GHG emissions.

Good results in terms of energy saving and avoided environmental impacts can be achieved through a correct choice of the energy technology among those available, and an accurate design of the selected technology that takes into account climatic conditions and buildings loads [5].

To correctly assess the energy and environmental advantages due to the installation of a RET for satisfying the cooling and heating demand of buildings, a life cycle approach should be followed, which includes the impacts/benefits during all the life cycle of the investigated system.

The Life Cycle Assessment (LCA), standardized by the international standards ISO 14040 [14] and 14044 [15] is a scientific methodology for assessing and comparing the energy and environmental performances of different energy technologies, including energy and material consumption, and emissions during the entire life cycle [16].

This paper presents the results of a simplified LCA applied for investigating the life cycle impacts of different solar assisted systems operating in two locations. The LCA was carried out by applying a user-friendly LCA tool [17], developed in the framework of the International Energy Agency SHC Task 48.

Such a user-friendly LCA tool allows for developing simplified analyses of solar assisted technologies in the early design stage, once energy consumption during the operation phase and the main equipment that constitutes the system are known.

Even though different simplified LCA tools have been developed in the scientific literature [18], as far as the authors are concerned, there are no LCA tools specifically developed to be applied to solar energy systems.

2. The LCA tool

A simplified LCA tool was developed for assessing and comparing the energy and environmental performances of different solar assisted plants, in different climatic conditions.

Thanks to its simple structure, this tool enables researchers operating in the field of SHC, both LCA practitioners and non-professional users, to compare the energy and environmental balances of SHC systems (with absorption or adsorption chiller) with those of conventional systems assisted by photovoltaic panels. The tool is freely available on the website: http://task48.iea-shc.org/.

The simplified LCA that can be carried out with the tool involves less cost, time and effort, but yet can provide similar results to a more detailed and costly LCA. In detail, the user can calculate energy and environmental impacts of SHC systems and compare them with conventional systems assisted by PV, by simply inserting data on the yearly energy consumed by the investigated systems, their useful life, and their main components.

There are four basic steps in the application of the LCA tool, as illustrated in Fig. 1. The visual approach of the tool allows users to model the system life cycle by using a clear and transparent structure. Input data, specific impacts, total impacts are reported in separate worksheets; therefore, each worksheet can be easily consulted or filled in. The LCA results are displayed both in tables and in figures and are referred both to specific life cycle steps (manufacturing, operation and end-of-life) and to the life cycle as a whole.

The tool is composed by the following worksheets, illustrated in an "index" page:

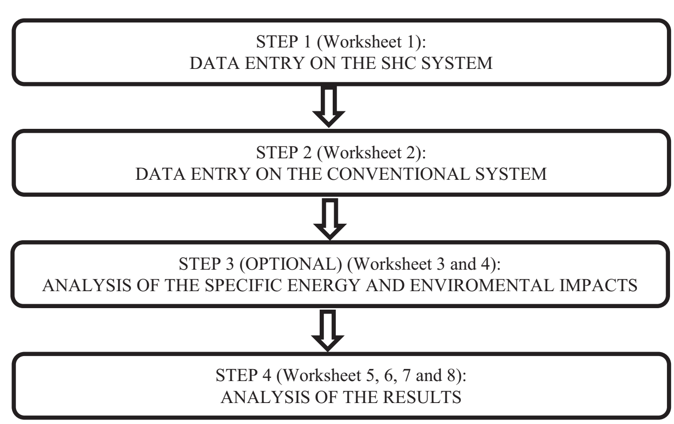

Fig. 1. Basic steps for the application of the LCA tool.