Building and Environment 87 (2015) 45–58

Contents lists available at ScienceDirect

Building and Environment

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

# The environmental performance of a building-integrated solar thermal collector, based on multiple approaches and life-cycle impact assessment methodologies

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ARTICLE INFO

*Article history:*
Received 24 October 2014
Received in revised form
21 November 2014
Accepted 10 January 2015
Available online 20 January 2015

*Keywords:*
Life Cycle Analysis (LCA)
Building-integrated solar thermal collectors
Endpoint and midpoint/damage approaches
Eco-indicator 99 (EI99) and IMPACT 2002+
Embodied energy and embodied carbon

ABSTRACT

In continuation of authors' previous study, the present investigation regards the comprehensive evaluation of the environmental profile of a patented building-integrated solar thermal collector, based on multiple Life Cycle Impact Assessment (LCIA) methodologies. The system has been developed and experimentally tested at the University of Corsica, in France and it consists of collectors integrated into building gutters. Three alternative configurations are examined by means of the LCIA methodologies Eco-Indicator 99 (EI99) and IMPACT 2002+ along with embodied energy and embodied carbon. Multiple approaches and scenarios are examined in order to evaluate the effect of several parameters on system environmental performance. The results, based on all the LCIA methodologies used, reveal that the configuration with collectors in parallel connection can considerably improve the environmental profile of the reference system (collectors in series). This impact can be further reduced by using systems with double absorber surface/output and/or recycling. On the other hand, the present investigation provides a critical comparison of the proposed system with other types of solar thermal and conventional heating systems. The primary energy and $CO_2$ savings (per month) related with the production of energy by the proposed BI solar thermal systems, instead of using a conventional heating system, are also presented.


## 1. Introduction

Building-Integrated (BI) solar systems are a new tendency in the building sector,[1] offering several advantages compared to the Building-Added (BA) configurations (e.g. higher esthetic value) [1]. Most of the literature studies about BI solar systems concern BI Photovoltaics (PVs) [2] while there is a small number of experimental and/or numerical investigations about real BI solar thermal systems [3,4]. Regarding Life Cycle Analysis (LCA) studies, most of them are about BA solar thermal collectors for domestic hot water [5–17] and passive solar walls [18].

LCA studies about BA active flat-plate collectors have been conducted by: 1) Kalogirou [5]: a solar water heating and a solar space/water heating system were evaluated (Nicosia, Cyprus). The energy for manufacture/installation was recouped in about 1.2 years and the payback time for the emissions ranged from few months to 9.5 years; 2) Streicher et al. [6]: two domestic hot water systems were studied. The energy payback time was found to be 1.4 and 2.1 years for the first and the second system, respectively; 3) Otanicar and Golden [7]: a nanofluid solar collector was compared with a conventional one (domestic hot water; Phoenix, Arizona, US). The nanofluid collector had lower embodied energy (≈9%) and approximately 3% higher pollution offsets than a conventional collector; 4) Carlsson et al. [8]: three solar collectors were examined (flat-plate, evacuated-tube and polymeric); based on EI99, IPCC and CED (Cumulative Energy Demand); the polymeric configuration showed the best environmental performance; 5) Rey-Martínez et al. [9]: a solar thermal installation (rural house in Valladolid, Spain) was studied by means of EPS 2000. The financial and environmental profits of the solar installation were compared with a natural gas boiler system.

Investigations concerning LCA of BA passive flat-plate collectors were performed by: 1) Kalogirou [10]: domestic thermosiphon

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[1] Some types of BI solar thermal systems exist several years ago; "new tendency" means that over the last years there is an increasing interest for BI solar thermal configurations (and in general, for BI solar systems) in the building sector (certainly, this interest begins from the research).

http://dx.doi.org/10.1016/j.buildenv.2015.01.011
0360-1323/

solar water heater (Nicosia, Cyprus); 2) Ardente et al. [11]: passive solar device for domestic use (Palermo, Italy; overall primary energy: 11.5 GJ). Based on [11], Ardente et al. also conducted a study with several scenarios [12]; 3) Marimuthu and Kirubakaran [13]: flat-plate collector (energy payback time: 2.3 years; carbon inventory: 44.3 kg for manufacture of collector materials).

Furthermore, Hang et al. [14] investigated evacuated-tube and flat-plate collectors (with auxiliary systems (natural gas; electricity) for Los Angeles, Atlanta and Chicago). The energetic/environmental payback periods for the solar water heating systems were less than half of a year. Crawford and Treloar [15] studied solar hot water systems in combination with electricity or gas vs. conventional systems (Melbourne, Australia). The solar hot water systems showed a net energy saving compared to the conventional systems after 0.5–2 years, for electric- and gas-boosted configurations respectively.

In addition, Smyth et al. [16] studied an integrated collector/storage solar water heater (Northern Europe, Ireland). The primary embodied energy of the collector materials was 2.94 GJ and the total embodied energy for the unit was 3.81 GJ. The total energy for the manufacture of the unit was recouped in less than 2 years. Moreover, Battisti and Corrado [17] studied an integrated collector/storage solar water heater (Mediterranean countries). The energy payback time and the $CO_2$ payback time ranged from 5 to 19 months.

The literature review reveals that most of the LCA studies about solar thermal systems for buildings concern: 1) BA configurations, 2) embodied energy/$CO_2$ emissions. Thus, there is a gap in the literature regarding LCA works about real BI solar thermal systems as well as about investigations based on “eco-point/single-score” LCIA methodologies. In addition, most of the LCA studies about solar thermal systems focus on the solar installation and they do not include a comparison with other systems (conventional and/or solar). The present study aims at filling the above mentioned gaps by investigating the environmental profile of a patented BI solar thermal collector by means of multiple LCIA methodologies: i) the endpoint oriented Eco-indicator 99 (EI99), ii) the combined midpoint/damage approach IMPACT 2002+, iii) Embodied Energy (EE) and iv) Embodied Carbon (EC) as well as by comparing the results with other types of systems (solar thermal and conventional). The present article, along with authors's previous study [19] provides a comprehensive environmental performance of the proposed BI active solar thermal system, based on multiple approaches and LCIA methodologies.

## 2. Materials and methods

For the implementation of the LCA, according to ISO 14040:2006 [20] and ISO 14044:2006 [21], the following phases are adopted: 1) goal and scope definition, 2) life-cycle inventory, 3) life-cycle impact assessment and 4) interpretation.

### 2.1. Functional unit and system boundaries

The whole system which includes 14 solar collectors and certain additional components (storage tank, pump, external tubes with their insulation, glycol) is considered as the functional unit. The boundaries include the whole system in terms of: material manufacture (for collectors and system additional components), manufacture of the collectors, system installation, use/maintenance, transportation and disposal.

### 2.2. System definition

#### 2.2.1. Technical characteristics of the studied configurations

The BI solar thermal system which is examined (Fig. 1) was developed and tested at the University of Corsica, in France. It is based on a patented solar collector for water heating [22], integrated into building gutters (high building integration with no visual impact: Fig. 1a). The solar collector is tilted 25° (Fig. 1a). The ducting connecting the house to the collector is hidden in the vertical drainpipe. One installation contains several connected modules. One module has around 1 m length and 0.1 m width for individual houses (larger modules can be developed for large-scale applications). The components of one unit (Fig. 1b) are: a highly-selective absorber, a glass cover, one tube for the flow of the cold water (lower insulated tube), one tube for the flow of the hot water (in thermal contact with the absorber), thermal insulation, external casing and gutter. More information about the materials of the system is given in section 2.3 while in Fig. 1c details about the whole installation are illustrated.

In Table 1, the basic technical characteristics and the performance of the studied systems are presented. Additional information can be found in Refs. [3,4,22–25]. System 1 is considered as the reference system, it is connected in series and the tubes (cold water tube and hot water tube) are at different levels (Fig. 1b). System 2 is the same with the reference system but the collectors are connected in parallel. System 3 is connected in series and it has the tubes at the same level (into the absorber). System 3 was numerically optimized to achieve better performance than the other two systems. Systems 1 and 2 were studied experimentally as well as numerically [3,24]. System 3 was studied only numerically [23,25] due to the fact that absorbers of this size with the tubes at the same level are not commercially available.

#### 2.2.2. Assumptions

- The calculations regarding outputs/inputs of Systems 1–3 refer to a system with 14 solar collectors (approximately 2 $m^2$ total solar absorber surface) and one 100 l tank (suitable for two persons).
- One unit of solar collector (Fig. 1b) and system additional parts include the materials/components that are presented in section 2.3.
- The impact of the processes for collector manufacture is incorporated into the LCA model as 27% of the impact which is related to the manufacture of collector materials, based on [7,10].
- The impact of system installation is incorporated into the LCA model as 3% of the total impact for the manufacture of collector/additional components, based on [7,10].
- Glycol is used as anti-freeze protection fluid. In Corsica the temperatures in winter are not very low [26]; thus, a proportion of 20% glycol in the glycol-water mixture is adopted.
- System use/operational phase includes: electricity for pumping/auxiliary heating, replacement of some parts of the system over its lifetime (one replacement of the glasses; one replacement of the storage tank; five replacements of the glycol), general maintenance of the system (cleaning, etc). The impact of the general maintenance is considered to be 10% of the material impact of the collectors [27].
- The transportation is conducted by a truck from the factory gate to the building and from the building to the disposal site. A total distance of 50 km is assumed for the transportation.
- For the disposal, landfill is adopted for most of the materials since it is the most common waste treatment technology in many countries [28]. Disposal includes: materials/components of all the collectors, system additional components, components