# Infield Output of a New Solar-Thermal Façade with Increased Architectural Acceptance

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## ABSTRACT

Increasing the solar fraction in building requires the extensive use of the building facade. The coverage degree and architectural acceptance need non-traditional shapes (isosceles trapeze and equilateral triangle) and colors (red, green, orange) of solar-thermal collectors, developed as building blocks for "lego-type" solar-thermal facade. The paper presents the results of the infield monitoring for a solar-thermal façade based on trapeze solar-thermal collectors. Results: groups of three serial collectors are efficient; during the cold and mild months the efficiency is close to the nominal efficiency; facades with parallely connected groups of three serial collectors are the best suited.

***Keywords***: solar-thermal facade, trapezoidal solar-thermal collector, infield efficiency, solar-thermal materials

## 1 INTRODUCTION

Increasing the share of renewables in the today's energy production formulated specific targets for the built environment as one of the largest consumer. The concepts of (Nearly) Zero Energy Buildings emerged thus as a need to meet the sustainability goal [1]. Solar energy convertors are key actors in the renewable-based energy mixes. Building integrated solar-thermal systems represents a well-accepted solar technology; however, increasing the share of thermal energy for domestic hot water and for heating asks for using also the highly visible places on a building, as the facades [2]. Solar-thermal facades require good conversion efficiency, considering the inherent losses in solar radiation incident on the modules, due to the vertical mounting; however, this can also be an advantage during hot seasons, by shortening the stagnation periods, thus increasing durability. An additional key pre-requisite is the architectural acceptance, as most of the traditional flat plate collectors have rather uniform geometry and colors, hardly acceptable if extensively implemented [3]. This is why a new flat plate collector was designed and developed, as a building block for "lego-type" solar-thermal facades, with various geometries. The collector has isosceles trapeze shape (0.67 m$^2$), and can be manufactured in a broad variety of colors (red, blue, green, granite, or their combinations) [4]. Environmentally friendly techniques (sol-gel) are used to obtain the dispersion that is sprayed at room temperature on the conditioned aluminum substrate. Additionally, self-cleaning thin films ($SiO_2$/$TiO_2$/Au nanoparticles) were deposited on the glazing and allowed the photocatalytic decomposition of organics, while slightly enhancing the optical properties of the solar glass substrate [5]. Combinations of commercial and novel dispersions used to develop the colored spectral selective absorber plates allow to develop a set of nine different prototypes, with nominal efficiencies up to 61.5% measured on the indoor testing rigs [6]. These prototypes were further used to develop a solar thermal façade, implemented in a temperate-continental mountain climate (Brasov, Romania: 45°40'08.6"N, 25°32'57.8"E, 600 m above the sea). The façade allows various interconnection architectures of the collectors (serial/parallel), aiming at validating a concept that supports easy mounting/dismounting and maintenance: groups of three trapeze collectors serially connected, delivered as such by the manufacturer and customized according to the façade design [7].

This paper presents the results of the infield monitoring of the new solar-thermal façade using an experimental setup consisting of trapezoidal flat plate solar-thermal collectors and commercial solar-thermal collectors for reference. Each solar-thermal collector is individually monitored in terms of inlet/outlet temperature of the thermal fluid and its mass flow. The coverage degree with rectangular and trapezoidal/triangular solar thermal collectors is comparatively analysed for the southern façade of a building. Based on experimental results, final conclusions related to the collectors' functionalities are presented.

## 2 METHODOLOGY

### 2.1 Solar thermal collector infield output

The infield output of a solar thermal collector (STC) is calculated with:

$$Q = \dot{m} \cdot c \cdot (t_o - t_i) \text{ [W]} \tag{1}$$

where,

$\dot{m}$ is the solar fluid mass flow [kg/s]

$c$ is the heat capacity of the fluid [J/(kg·K)]

$t_i$, $t_o$ are the inlet, outlet temperatures [°C]

## 2.2 Solar thermal collector infield efficiency

The efficiency of a solar thermal collector (STC) is calculated with:

$$\eta = \frac{Q}{G_n \cdot S_a} \cdot 100 \; [\%] \qquad (2)$$

where,
$Q$ is the STC infield output [W]
$G_n$ is the received global solar irradiance [W/m$^2$]
$S_a$ is STC absorber surface [m$^2$]

The received global solar irradiance ($G_n$) can be measured in the STC plane or can be calculated based on measurement of the beam (B), global horizontal ($G_h$) and diffuse horizontal ($D_h$). In the paper it is denoted $G_v$ for vertical STC and $G_t$ for optimally tilted STC.

# 3 CASE STUDY

The upper part of the southern façade of a traditional house is considered to evaluate the possible coverage with commercial (Figure 1) and with novel triangular and trapezoidal (Figure 2) solar thermal collectors.

Figure 1: Traditional house with commercial solar thermal collectors installed on the southern façade.

In the case of commercial STCs, only three collectors can be fitted because of theirs rectangular shape and quite large height (2070 mm) and width (1145 mm), resulting a coverage of 7.11 m$^2$. In the case of triangle STC having equal sides (700 mm) and trapeze STC equivalent in surface with three triangle STCs, 49 triangle STCs and 8 trapeze STCs can be arranged, resulting a coverage of 15.47 m$^2$. Thus the active surface can be easily doubled.

Figure 2: Traditional house with triangular and trapezoidal solar thermal collectors installed on the southern façade.

# 4 EXPERIMENTAL SETUP

The beam (B), global horizontal ($G_h$) and diffuse horizontal ($D_h$) solar irradiance are measured onsite using a Kipp&Zonen Solys2 Sun Tracker, equipped with two CMP22 pyranometers (0.5% accuracy) and a CHP1 pyrheliometer (1% accuracy). Based on, the global solar irradiance received in the plane of vertical ($G_v$) and tilted ($G_t$) solar thermal collector are calculated.

The experimental setup is developed based on an outdoor testing rig (Figure 3). On its Southern façade are installed one commercial and nine trapezoidal flat plate solar thermal collectors. Another two commercial solar thermal collector (one flat plate and another one with evacuated tubes) are installed on the rooftop, at an optimal tilt angle (35°) established to obtain the maximum annual thermal energy output. The storage tanks, pumps, controllers and data loggers are located at the interior of the testing rig, the hydraulic scheme is presented in Figure 4.

Figure 3: Outdoor testing rig for solar-thermal collectors

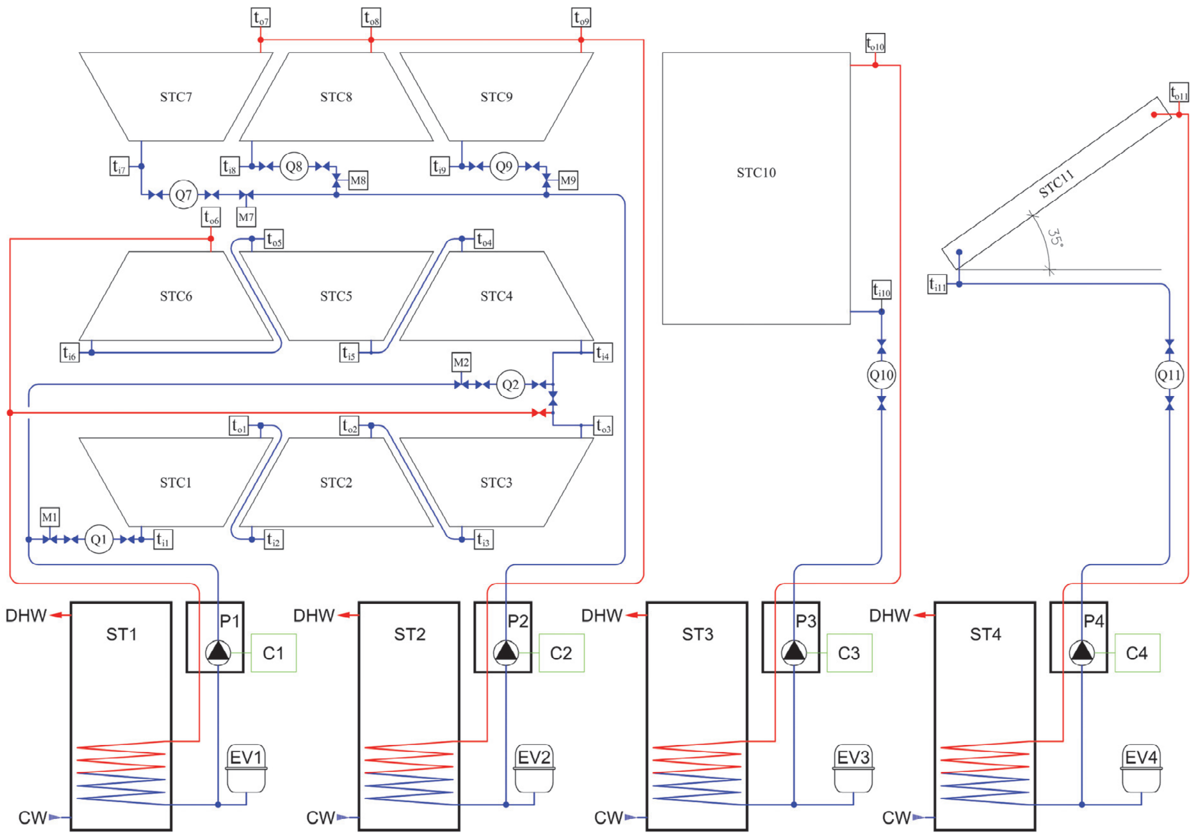


Figure 4: Hydraulic scheme of the outdoor testing rig for solar-thermal collector.

The STCs 1 to 9 are of trapezoidal shape (prototypes) and STCs 10 and 11 are rectangular (commercial) having a nominal efficiency of 85.1%. STCs 1 to 10 are vertically installed on the southern façade of the outdoor testing rig and STC 11 is optimally tilted at 35° on the rooftop. The first group of three trapezoidal STCs (1, 2 and 3) are serially connected to heat the domestic hot water (DHW) in the storage tank 1 (ST1). The second group of three trapezoidal STCs (4, 5 and 6) are also serially connected and this group can be serially or in parallel connected with the first group. The upper three trapezoidal STCs (7, 8 and 9) are parallely connected to heat the domestic hot water (DHW) in the storage tank 2 (ST2). The commercial STCs (10 and 11) are separately connected to storage tanks ST3 and ST4. Inlet ($t_i$) and outlet ($t_o$) temperatures are measured for each STC with Pt100 temperature probes. The fluid (antifreeze solution) mass flow in each circuit is measured with flowmeters (Q) and can be adjusted with the motorized valves (M). Hydraulic pumps (P) are driven by the controllers (C) based on the temperature of the STCs and STs. The expansion vessels (EV) compensate the variation of the fluid volume in the solar circuits.

## 5 RESULTS AND DISCUTIONS

Based on the beam and horizontal diffuse solar irradiance measured onsite in a sunny day (Nov 21st 2016), the global available solar irradiance (G) is calculated along with the global solar irradiance in the plane of the tilted solar thermal collector ($G_t$) and in the vertical plane of the solar thermal façade ($G_v$) (Figure 5). As expected, the vertical façade received more solar energy in comparison with the tilted one, due to its advantageous elevation.

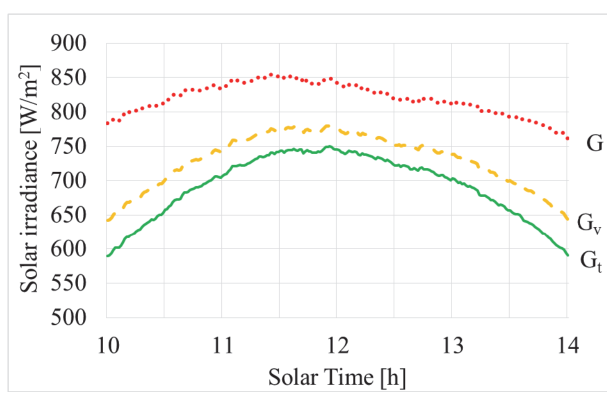


Figure 5: Global available (G) and received solar irradiance in the plane of the tilted ($G_t$) and vertical ($G_v$) STC.


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The temperatures at the inlet ($t_i$) and at the outlet ($t_o$) of the STCs 1, 2, 3, 10 and 11 are plotted along with the outdoor air temperature ($t_a$) in Figure 6, showing that theirs serial connection is beneficial in increasing the general outlet temperature when targeting DHW (60°C).

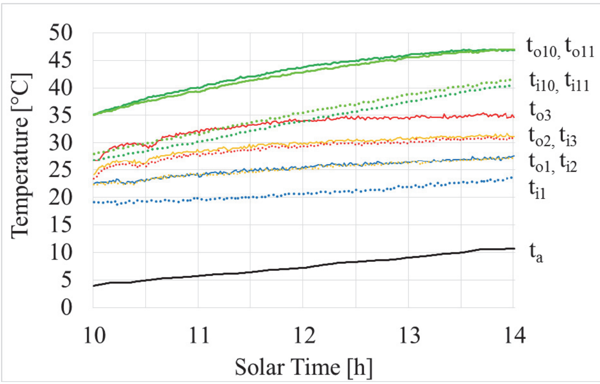


Figure 6: Inlet ($t_i$) and outlet ($t_o$) temperatures for STCs 1, 2, 3, 10 and 11 and the outdoor air temperature ($t_a$).

The efficiencies of the STCs were calculated and plotted in Figure 7 where there is visible the efficiency drop for the 2nd and the 3rd serially connected STC, especially in the morning when outdoor air temperature was significantly lower than the STCs temperatures.

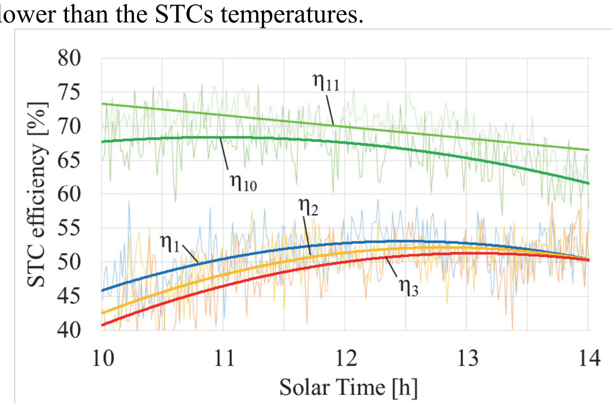


Figure 7: Efficiencies for STCs 1, 2, 3, 10 and 11.

When STCs are furthermore serially connected, the outlet temperature increases but the temperature gradient is lower because of the efficiency drop with the temperature increase.

## 6 CONCLUSIONS

The coverage degree is comparatively analyzed with the same facade covered with triangular & trapezoidal (prototypes) and rectangular (commercial) solar thermal collectors; increases up to 218% are demonstrated for South-facing façade of a traditional single family house.

The analysis of the experimental data outlines:

- the vertical position of the façade increases the amount of the received solar energy in the winter time in comparison with the optimal tilted STC;
- this vertical position is beneficial also for summer time when the received solar energy is lower, preventing thus the overheating of the large surface of the solar façade;
- groups of three serially interconnected collectors are efficient;
- the infield thermal energy response is close to the nominal efficiency, particularly during the cold and mild months;
- the addition of a fourth, fifth ... collector results in a lower overall efficiency, particularly true for the cold seasons.

Based on these results, novel façades are proposed, with parallely connected groups of three (serially connected) trapezoidal solar thermal collectors. Also, a further concept on seasonal changes in the collectors' interconnection is proposed.


## ACKNOWLEDGMENTS

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