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Urban acceptance of facade integrated novel solar thermal collectors

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Abstract

Architectural acceptance of façade integrated solar-thermal arrays requires novel solutions for the flat plate solar thermal collectors, in terms of shape, size, colour and functionality. The paper presents a novel concept of solar-thermal arrays with variable geometry, based on non-rectangular collectors; different shapes and sizes are analysed and their adaptability in developing arrays with various geometries is discussed. Two "unit" shapes are proposed (equilateral triangle and isosceles trapeze), based on which various geometries can be developed; the size range of the collectors is discussed, along with the tubes' design for the inner circulation of the water based working fluid. Several examples of façade and roof integrated arrays are presented, outlining the versatility of the proposed solution.

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Keywords: façade integrated solar-thermal arrays; solar thermal collector shape; solar thermal design; architectural acceptance

1. Introduction

Considering the international trends, particularly the EU major documents on energy (SET Plan, the 20-20-20 and the Energy Efficiency Directives), specific actions are required for clean, sustainable, efficient and affordable thermal energy production, particularly for buildings' use, as domestic hot water (DHW), heating and cooling. Therefore, on-site production of domestic hot water (DHW) and partially of heat using solar energy represents and alternative for satisfying these requirements by developing novel solar-thermal systems with broad architectural acceptance.

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Solar-thermal systems are extensively investigated from more than 50 years and efficient solutions, adapted to various applications (heating, cooling, DHW, power production) are already in the market, [1]. The large majority of these systems were designed and optimized considering functionality and engineering aspects but, for large scale implementation at community level additional pre-requisites should be satisfied. A highly cited pole, answered by over 170 professionals outlined that the usual black or dark blue-shaded collectors, with rectangular shape are not welcome on visible places as facades, balconies, architectural objects, [2].

Thus, several research directions can be now identified, for developing:

- Multi-functional solar energy conversion systems, traditionally installed on the roofs and terraces, where there are less constraints of urban acceptance, as it is the combination of flat plate solar-thermal collectors for air and for water heating with PV/thermal (PV/T) modules and regular tiles, [3];
- Novel solutions integrated in the buildings envelope, by actually “hiding” the convertors, as the massive solar-thermal collectors, using concrete, bricks or gravel as heat storage systems, [4], or colored mild steel sheets integrated in the facades, [5,6]; another development recently reported is on novel solar-thermal collector, drain pipe integrated, thus practically invisible from the ground level, [7,8];
- Active transparent or translucent facades with integrated PV/T modules, [9,10] or with transparent tube solar thermal collectors integrated in balconies or stairwells, [11,12];
- Active opaque facades, [13], containing flat plate solar thermal collectors (FSTC).

In the temperate climate, FSTC can insure up to 80% of the DHW need, but these data are influenced (beside the input radiation) by the mounting conditions that will strongly affect the solar energy gain and the losses. Usually in Central and SE Europe a tilt angle of $35^o…45^o$ allows the maximal solar energy gain for collectors facing South, thus facades mounting (at a tilt angle of 90^o) will decrease the input radiation, thus the yield. On the other hand, vertical mounting has the advantage of avoiding overheating during summer, when heating is no needed and DHW use may be diminished (holyday seasons). Façade vertical mounting has additional positive effects on the building: it insures insulation and has a soundproof effect, while the indoor comfort is very little affected, with about 1^oC temperature increase during summer, [14]; stagnation conditions are unlikely and active drive can be done at rather low overpressure (usually 2 bar); if mounted from the construction stage, façade finishing can be skipped under the FSTC arrays, etc. Thus, from engineering point of view, the development of solar-thermal arrays represents a possible asset.

The development of active solar-thermal facades is thus limited by the architectural requirements; plenty of research was devoted to developing colored solar-thermal coatings and promising results are reported, covering both alternatives: colored absorber plate and/or colored glazing, [15]. All the reported results are making reference to the traditional rectangular shape of the collectors and this represents another drawback, both from aesthetic and functional points of view; facades have very different shapes and the position of the opaque and transparent parts is highly different, giving individuality to the buildings. Therefore, developing arrays well covering the available space requires a multitude of shapes and this can be done only if one steps out from the rectangular geometry.

This paper presents a novel concept on developing solar-thermal arrays, based on colored FSTC with various geometries (triangle, trapeze, square, and hexagon). These lego-type arrays allow filling facades with very different shapes and, by integrating colored FSTC, gain architectural acceptance. Proposals for novel facades are presented, along with different mounting solutions.

2. The concept

The list of design specifications covers the “building blocks” – the collectors, their assembly – the array and the solar-thermal system:

- Flat plate solar thermal collectors:
  - Various polygonal geometries;
  - Various colours, with good corrosion/erosion resistance;
  - Using the current manufacturing technologies;
  - Market accepted efficiency;
  - Low cost, not exceeding the market EUR/W cost.
- Solar-thermal arrays:

  - Covering various wall configurations;
  - Flexible design, of lego type, matching collectors with different shapes and/or colours;
  - Fixed or with limited tracking;
  - Mounting should allow equilibrated hydraulic pressure;
  - Urban/architectural acceptance.
- Solar Thermal Systems:
  - Using traditional storage, pumping and piping systems;
  - Easy maintenance.

3. Results and discussions

3.1. The solar-thermal collectors and arrays

For building up a façade with a high flexibility degree in terms of shape and design, the solar-thermal collectors should be different than the regular "rectangle" shape; still, a "unit" shape should be found, based on which the other geometries can be derived and in this view, highly symmetric geometries are preferred. Additionally, the unit shape should not be too large, as increasing the dimensions reduces the coverage degree of small facades. On the other hand, the hydraulic limitations impose an inferior size limit, below which pressure drop in the tubes is significant. Preliminary calculations showed that polygonal geometries with sides of 70…120 cm may suite the purpose (I. Visa *et al.*, patent proposal no. A/00156/18.02.2013).

Basically, these pre-requisites are well satisfied by the equilateral triangle, Fig. 1a, allowing to further building up isosceles trapeze and regular hexagons (with the corresponding increased dimensions). On the other hand, if compact larger assemblies are required, the better choice for the unit shape is the isosceles trapeze, with the advantage of reducing the costs (as compared to three interconnected equilateral triangles) and increasing the reliability, but having the drawback of a single colour of the collector, Fig. 1b. Both unit shapes can also include rectangular geometries, with sizes ranging from 70…120 cm for the width and 140…240 cm for the length.

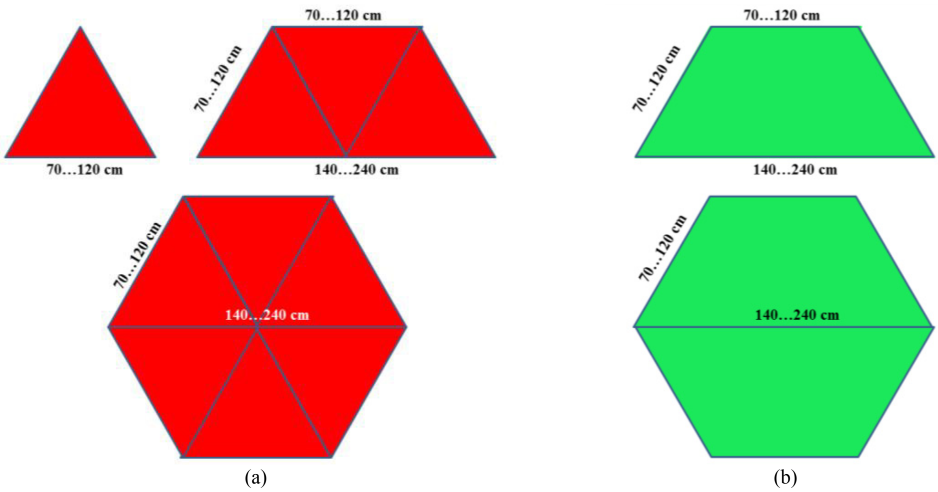
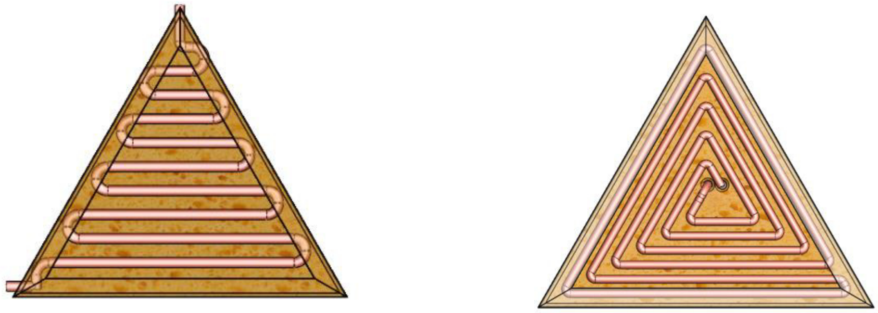


Fig. 1 Novel unit shapes of the FSTC: (a) equilateral triangle and (b) isosceles trapeze, and examples of derived geometries

The new collectors' shapes require novel solutions for the tubes. These should collect as much heat as possible from the absorber plate but also should allow interconnecting the collectors according to the array's design. Few possible solutions are hereby presented but there are many more that should be now tested.

For the triangle unit the obvious solution is with the in-/outlet on the corners, Fig. 2a. This is a feasible approach especially for serial connections of a limited number of FSTC. In-field studies on commercial FSTC showed that there is a limited number of collectors that can be serially interconnected (up to 5) and above this limit the efficiency drastically drops as the in/out temperature difference is too low. Considering the reduced size of the novel triangle collectors, preliminary estimations showed that the number of serially connected collectors can be higher but it is limited.

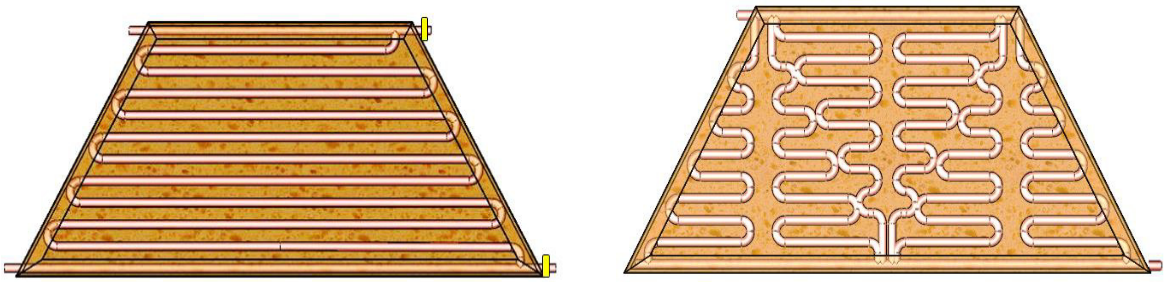
An alternative is proposed, that allows parallel or serial connection with the same likelihood, based on the in-/outlet that are positioned close to the mass centre of the collector, Fig. 2b. The closed loop type of the tubes design allows, according to the unit size and tubes diameter, various geometries, insuring a high collection degree of the heat delivered by the absorber plate. Calculations showed that for a 1/2" tube, a distance of 10…12 cm is enough for avoiding heat losses between the absorber plate and the working (liquid) fluid.



(a) (b)

Fig. 2. Tubes design for the triangle shape unit: (a) inlet/outlet on the corners and (b) inlet/outlet in the mass center

When considering the isosceles trapeze unit shape, the variety of tubes design can be very high. Two proposals are presented in Fig. 3.



(a) (b)

Fig. 3 Design of the tubes in the trapeze unit shape: (a) serpentine and (b) novel design

The serpentine in Fig. 3a is mounted inside a collector that can have four in/outlet connections; according to the mounting requirements on each of the trapeze basis one will be blinded, leaving a regular one-to-one inlet/outlet. The novel design proposed in Fig. 3b derives from the traditional parallel tube design but has significantly enhanced heat coverage of the absorber plate. Combinations of these two serpentine types are also possible using tubes with different diameters for hydraulic equilibration.

By assembling the collectors, arrays are formed, following the opaque part of the facades, ideally South facing.

As already explained, the FSTC design imposes flexibility for parallel and serial interconnection and this can be supported also by flexible pipes in the circuit outside the collector. Mounting the array should be done not directly on the façade but on a single frame embedding all the FSTC. This protects the façade and allows the pipe circuit without aesthetical impediments.

Frame mounting is particularly important when also considering tracking. Tracking could be done on a limited angle as for individual modules, strings of modules or for the entire array, by moving the frame, and is mainly considered for avoiding over-heating during hot summer days and less for increasing the energy gain.

In terms of colours, the group working in the development of the novel FSTC has solutions for coloured glazing and coloured absorber plates. Thin multi-stacked films of TiO_2 with different thickness and porosity (thus different refractive index and reflectance) were deposited on microscopic glass and on solar glass exhibiting various colours from dark red to violet, while preserving transmittance values over 80% and having very low reflectance (below 2%), [16]. Further work is done for other glazing colours using iron and cobalt oxides. Coloured absorber plates were developed as thickness insensitive solar selective coatings, based on cermets deposited on aluminium foil; the cermets consist of a highly porous alumina matrix infiltrated with inorganic pigments (Fe_2O_3, V_2O_5 and CuS) and with gold nano-particles. A corrosion protective TiO_2 very thin layer insures the durability of the coating. Competitive bright red absorber plates were obtained having high solar absorptance (α_S) and low thermal emittance (ε_T), and a spectral selectivity (S) above 9 ($S = \alpha_S / \varepsilon_T$), with the structure: $Al/Al_2O_3/Fe_2O_3/Au/TiO_2$. The coatings for the glazing and for the absorber plate are obtained using robotic spray pyrolysis deposition, an open air technique that allows depositions on large surfaces, by using low cost precursors and mild process conditions, being thus up-scalable.

3.2. The solar-thermal facades

Mounting the coloured lego-type solar thermal arrays has a high degree of flexibility and can contribute not only to the reduction in the fossil fuel and greenhouse gases but can increase the acceptance of the blocks of flats developed in the ’60…’80, which have a highly monotonous design. The main use of these arrays is for DHW, using as backup sources the already existent utilities systems.

Several proposals are presented in Fig. 4:

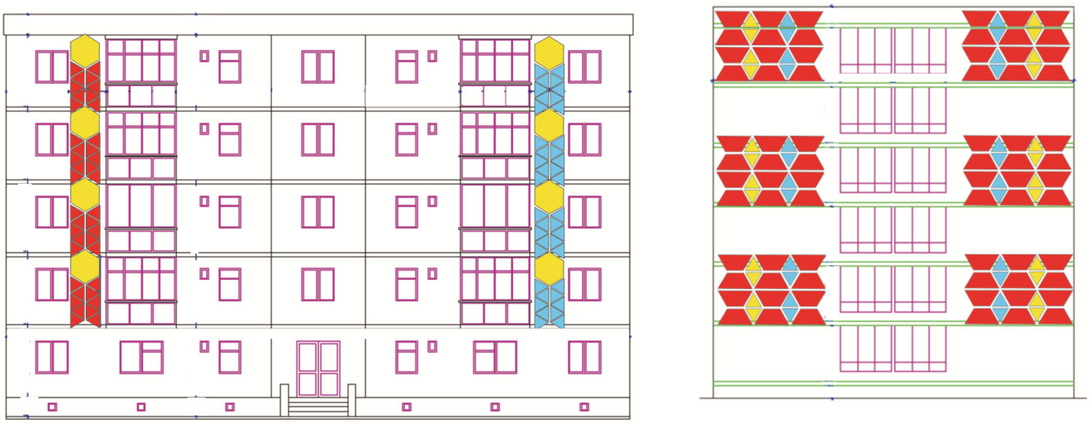


Fig. 4 Scaled representation of solar thermal arrays with trapeze and triangle FSTC

The versatility of the method is better proved when the solar-thermal arrays are mounted on residential buildings, as the pictures in Fig. 5 show.

These type of facades can also accommodate PV arrays, as 100…280W_p triangle PV modules are already on the market, with dimensions in the size range of the FSTC proposed in this work.

(a) (b)

Fig. 5 Scaled representations of lego arrays integrated in residential buildings: (a) façade integration; (b) roof integration

The lego-type solar-thermal arrays represent solutions developed in the *EST IN URBA* cooperation project, financed by the Romanian Agency of Research. In the end of the project one array will be installed on one building façade in the R&D Institute of the Transilvania University in Brasov. The Institute consists of 11 low energy buildings, with three levels (basement, ground floor and 1st floor, with an overall surface 1350 m^2), that have large glazed facades facing South. Each building acts as a testing stand and have/will have various renewable energy mixes for meeting the thermal and power demand, [17], aiming at the Zero Energy Building Status.

The location is in a mountain region, with temperate climate having rather cold winters, with temperatures down to -20^{o}C (for on average of 12 days per year) and mild summers with temperatures up to 32^{o}C.

A comparative analysis of the on-site solar radiation data (direct, diffuse) and of the values generated by METEONORM showed large differences, especially in the winter months (November – February) therefore in the design of the solar energy conversion systems, on-site weather data are used.

Fig. 6 Scaled representations of design solutions of lego-type solar thermal arrays integrated in a laboratory building of the R&D Institute of the Transilvania University of Brasov, Romania

The solar thermal arrays are designed to insure the DHW for the building and, during summer, the excess heat can be used in the solar-cooling installation. So far, design solutions were developed and are under calculation for identifying the optimal set up in terms of DHW yield and energy consumption for the forced circulation. Several design solutions are presented in Fig. 6.

According to the needs, the façade(s) can be fully or partially covered and the aesthetical effect is not so much depending on the actual geometry of the array but on the non-conventional shape of the FSTC and of their colours. As the proposed design solutions show, several assemblies of 2 or 3 FSTC are repetitive and further work will be devoted to analysing the options of delivering these assemblies by the manufacturer, thus supporting fast and accurate mounting of the array.

The optimised façade, to be installed in 2014 will also act as a dissemination tool, supporting a broader implementation of the solar thermal systems at the communities' level.

4. Conclusions

The development of active opaque facades, including solar thermal collectors requires the development of efficient convertors with high architectural acceptance.

The paper presents a novel concept of solar thermal arrays, based on unit shapes of equilateral triangles and/or isosceles trapezes.

The tube design for the water-based working fluid can follow the regular serpentine type but alternative solutions are presented, that insures large heat coverage and allows serial and parallel connections in various positions and assemblies.

The non-conventional shapes are completed with coloured glazing or absorber plate, leading to a practical infinite variety of solutions that can be implemented on blocks of flats, residential or office buildings and are supporting the more extensive development of sustainable communities.

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