EuroSun2026

# EXPERIMENTAL AND NUMERICAL STUDY OF EVACUATED TUBE SOLAR COLLECTOR WITH INTEGRATED STORAGE AND INTERNAL HEAT EXCHANGER


## Summary

This study presents an experimental and numerical analysis of evacuated tube solar collectors with integrated storage and internal heat exchanger. The solar thermal installation is located in North-West France and used for heating a livestock farm building. It is instrumented and monitored for two years. In parallel, a model is developed using TRNSYS to simulate temperatures at different points in the solar field and recovered thermal energy. A sensitivity analysis is performed using the Morris method to identify the most influential parameters of the model. These parameters are later identified using mono-objective optimization for selected climate and operating experimental data. Mean Absolute Percentage Error (MAPE) on recovered thermal energy of the calibrated model is less than 11%. A good agreement is also observed between simulated and measured temperatures within solar collector tanks with MAPE less than 5%.



*Keywords: Evacuated Tube Solar Collector, TRNSYS, Sensitivity analysis, Model calibration,*

*Field of application for the findings: Solar Thermal systems design characterization*

*Addressed audience: Researchers and Engineers*


## 1. Introduction

Evacuated tube solar collectors (ETSCs) are a mature solar thermal technology that offers good performance, particularly under low irradiance and cold climates (Zambolin and Del col, 2010). Among ETSC technologies, Water-in-Glass (WiG) tubes, which operate through natural thermosiphon circulation, are most adapted for integrated storage configuration. For instance, Gambade et al. (2023) monitored the performance of 16 WiG-ETSC used for hot water provision of a veal farm. In addition, they modeled this solar field using TRNSYS and reported a good agreement of simulations against experimental data measured over periods of six months, with Mean Absolute Percentage Error (MAPE) less than 8.5%. While thermosiphon flow is directly used as solar hot water in this set-up, a variant of this technology includes a heat exchanger in the storage tank to separate thermosiphon solar water from another heat transfer fluid (HTF). Studies on the performance of these devices are scarce. Ghaderian et al. (2017) used a similar device but only for solar HTF characterization. This study aims to model the performance of ETSC with integrated storage and internal heat exchanger in operational conditions, through a case of a monitored solar thermal installation.

## 2. Methodology

The tested set-up consists of a solar collector field made of 14 integrated collector-storage (ICS) units, fully south-oriented with a tilt angle of 45°. The field is designed for heating pig rearing building located in North-West France [47°11'11"N, 0°43'00"W]. Each unit consists of 30 WiG-ETSC attached to a horizontal 300L cylindrical tank. The latter contains a 15m spiral coiled heat exchanger (HEX) (see Figure 1b), through which flows HTF separately from the stagnant solar water. The HEX of each unit is linked to the next so that HTF is gradually heated through the field before entering a 1 $m^3$ hot water storage (maintained above 45 °C). The solar field pump has a constant rate and is activated once temperature difference between stagnant solar water of last tank and hot water storage is higher than 4 °C. Temperature is monitored at 13 locations in the solar field with thermocouples and HTF flowrate is measured with flowmeter. Weather station located nearby the solar field measures environmental parameters. All data is logged online since March 2024 every 300 s.

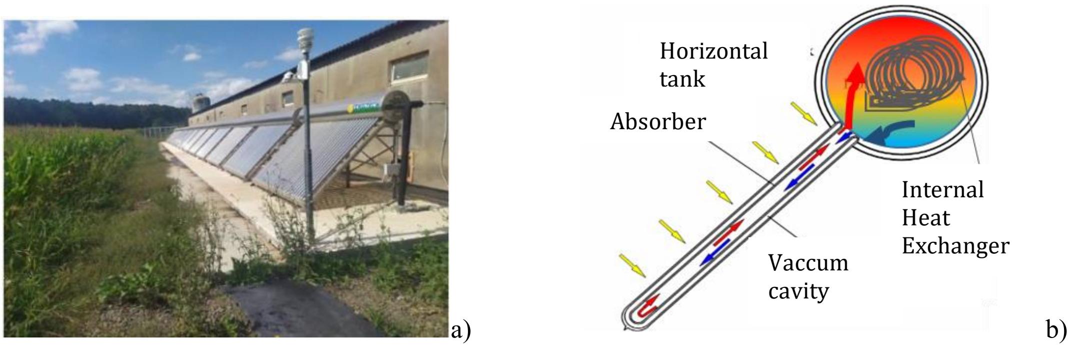


**Fig. 1: View of solar field and weather station (a) – Cross section of ETSC-WiG unit (b)**

The set-up is modeled on TRNSYS 18 software. The ISC unit model is assembled with a Type 71 for ETSC and Type 60 for the horizontal tank. The thermosiphon flow is calculated using the empirical correlation of Budiharjdo et al. (2007). Within the horizontal tank, a special attention is given to the discretization of the tank volume relative to the HEX length following Unrau (2017) work. The global model includes 14 ISC unit models that are linked by HEX outlet temperature and flowrate. Solar irradiance GHI, ambient temperature and HTF flowrate and HTF inlet temperature are used as simulation input. The model simulates temperature variations at various locations and recovered solar thermal energy.

A global sensitivity analysis is carried on the model to identify the most influential parameters on the solar field performance, among an initial set of 10 parameters related to evacuated tube efficiency, thermosiphon flow, tank thermal losses, heat exchanger and environment. Here, the Morris one-at-a-time method is applied using Python's SALib library coupled to TRNSYS model. The analysis is performed on the recovered solar thermal energy. Once identified, the values of most influential parameters are then estimated using Powell algorithm in Python's Pymoo library. Similarly to Yang et al. (2023), a weighted MAPE objective function is minimized:

$$WMAPE_{\_max} = \frac{1}{N_{days}} \sum_d \frac{\left|E_{exp}^d - E_{sim}^d\right|}{\max\left(E_{exp}^d\right)} \quad \text{(eq. 1)}$$

## 3. Results

Analysis is carried out for 14 summer days (from June 23rd, 2024, to July 7th, 2024). The GHI profile indicates clear sky conditions with cloud passages (see Figure 2a). The HTF flowrate is mostly continuous through day and nighttime around 800 kg.h$^{-1}$. The solar thermal energy recovered during this period is 4476.6 MJ.

Sensitivity analysis results are presented in Table 1 for four parameters. The elementary effect coefficient μ* shows that a0 (optical efficiency of ETSC), a1 (linear thermal efficiency of ETSC) and U (overall heat loss coefficient of the horizontal tank) and albedo have the strongest effect on model output. The estimated values of these parameters (see Table 1) agree with the previous ones obtained by Gambade et al. (2023) on a similar ETSC. Here, the objective function converges at WMAPE = 6.91 %. Solar thermal energy is well predicted from day to day, with a daily MAPE of 10.9 % (see Figure 2b). Over the period, simulated solar thermal energy is 4470,41 MJ and matches well with experimental energy. In addition, a comparison between simulated and measured average temperature in the horizontal tank of the 7th ISC unit (middle of serie) is shown in Figure 2c. The daily dynamic is well predicted by the model, even though the maximal temperature is slightly underestimated. Overall, the MAPE is 4.68 %. Similar results are obtained for other locations in the solar field.

**Tab. 1: Sensitivity analysis results and estimated values of four influencing parameters**

| Parameter | a0 | a1 | U | albedo |
|---|---|---|---|---|
| μ* | 1269.23 | 572.25 | 88.20 | 268.48 |
| σ | 64.75 | 61.54 | 6.11 | 58.83 |
| Estimation | 0.63 | 1.942 [W.m$^{-1}$.K$^{-1}$] | 0.572 [W.m$^{-2}$.K$^{-1}$] | 0.32 |

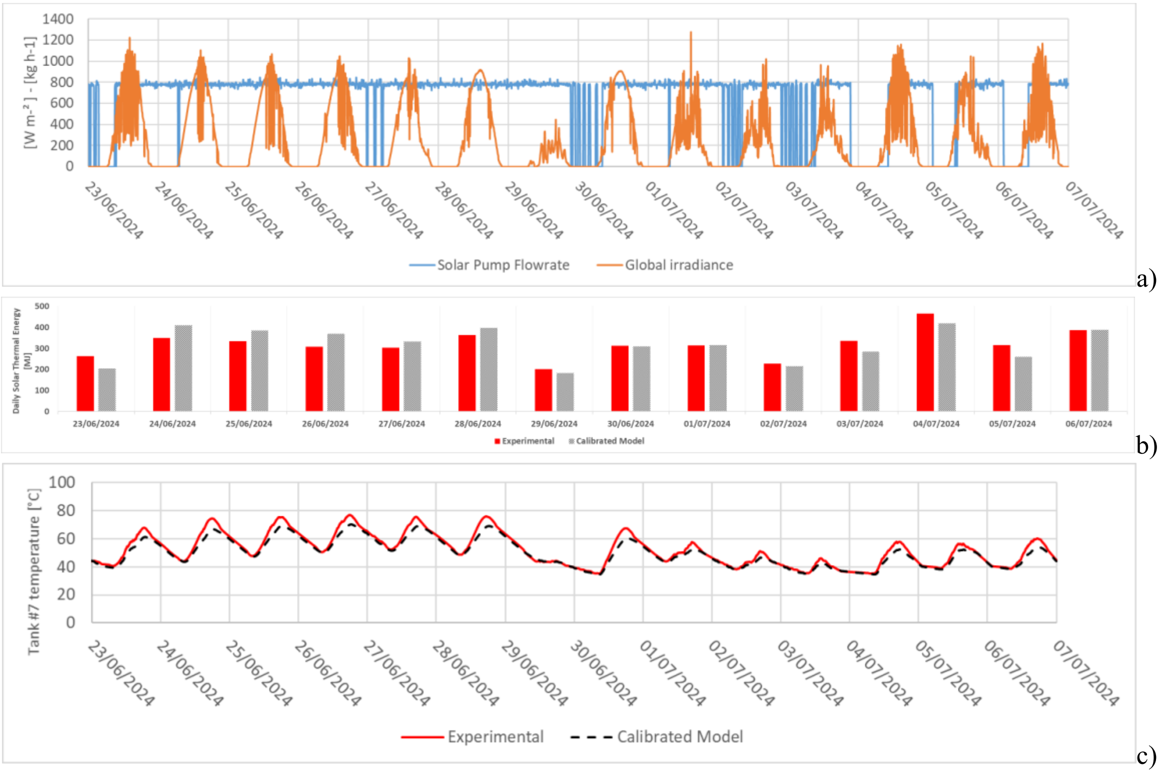


**Fig. 2: GHI and flowrate data input (a), simulated and measured daily energy (b), simulated and measured average temperature within the storage tank n°7 (c)**

## 4. Conclusions

This work presented the experimental performances of ETSC with integrated storage and internal heat exchanger in operational summer conditions and compared them with a numerical model developed in TRNSYS. After sensitivity analysis, some parameters were calibrated and a good agreement is found between simulation and experimental data. Further work consists in evaluating the performance of the set-up under miscellaneous weather and operating conditions and in validating the model.

## 5. References

Budihardjo, I., Morrison, G.L., Behnia, M., 2007. Natural circulation flow through water-in-glass evacuated tube solar collectors. Solar Energy. 81(12), 1460–1472.

Gambade, J., Noël, H., Glouannec, P., Magueresse, A., 2023. Numerical model of intermittent solar hot water production. Renewable Energy. 218, 119368.

Ghaderian, J., Sidik, N.A.C., Kasaeian, A., Ghaderian, S., Okhovat, A., Pakzadeh, A., Samion, S., Yahya, W.J., 2017. Performance of copper oxide/distilled water nanofluid in evacuated tube solar collector (ETSC) water heater with internal coil under thermosyphon system circulations. Applied Thermal Engineering. 121, 520–536.

Unrau, C., 2017. Numerical investigation of one-dimensional storage tank models and the development of analytical modelling techniques. McMaster University.

Yang, X., Ji, Y., Gu, J., Niu, M., 2023. An electricity consumption disaggregation method for HVAC terminal units in sub-metered buildings based on CART algorithm. Buildings. 13(4), 967.

Zambolin, E., Del Col, D., 2010. Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions. Solar Energy. 84(8), 1382–1396.