# SOLAR TRACKING SIMULATOR DEVELOPMENT FOR SOLAR COLLECTOR TESTS

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***Abstract***

Our department has been commissioned to carry out stress and energy tests of vacuum tube solar collectors recently developed in Hungary. In order to be able to carry out the energy tests, we have developed and installed an outdoor solar tracking simulator equipment set, accompanied by a matching computer assisted measuring system. We also developed a test system based on the standard MSZ EN 12975-2:2006 (E). With the solar simulator built, we tested vacuum collectors and issued evaluation reports on the results. Our tests were carried out between October 2006 and November 2007. The necessary investment was implemented with the support of the West Pannon Regional Development Council.

**Keywords:** solar energy, vacuum tube solar collectors, solar tracking simulator, computer assisted measuring system, energy tests.

## *Összefoglalás*

Tanszékünk új fejlesztésű, hazai vákuumcsöves napkollektorok terhelési és energetikai ellenőrző vizsgálatainak elvégzésére kapott megbízást. Az energetikai vizsgálatok elvégzéséhez kifejlesztésre került egy külsőtéri napkövető vizsgáló berendezés (szolár szimulátor) és a hozzá tartozó számítógépes mérőrendszer (4. és 5. ábra). Az MSZ EN 12975-2:2006 (E) szabvány alapján vizsgálati módszert dolgoztunk ki. A megépített szolár szimulátorral három különböző konstrukciójú vákuumcsöves kollektort teszteltünk, az eredményekről záró szakvéleményt adtunk. A mért paramétereket és mérési pontokat a 4. ábra mutatja. A szükséges beruházások a Nyugat-dunántúli Regionális Fejlesztési Ügynökség támogatásával valósultak meg.

A kialakított hőtechnikai mérőrendszer napkollektor-egységek terhelés vizsgálatára, a kollektorhatásfok és a termelt hőenergia mennyiség meghatározására, valamint összehasonlító mérésekre alkalmas. A szimulátoron egyszerre két kollektor-egység vizsgálható, melyeket a napkövető szervo rendszer képes folyamatosan a nap felé fordítani, azaz síkjukat állandóan a nap sugaraira merőleges irányban tartani. A vizsgálatok ideje alatt az adatgyűjtő számítógép regisztrálja a kollektorok által termelt hőmennyiséget, a napsugárzás intenzitását és az egyéb időjárási adatokat. Az elvégzett vizsgálatok két fő csoportra oszthatók: a termikus és mechanikai terhelhetőség vizsgálatára és a hőteljesítmény-vizsgálatra. A terhelési vizsgálatok során elvégeztük a kollektor-egységek belső nyomás-tesztjét, a magas hőmérsékleti ellenállás tesztjét, a külső-belső hősokk tesztet, az esővíz-áteresztés, fagyállóság és leüríthetőség vizsgálatát, valamint a sugárzás-tűrés tesztet. A hőteljesítmény-vizsgálatban meghatároztuk a kollektorok kimenő teljesítményét, valamint felvettük az egyes típusok kollektorhatásfok-görbéjét.

A vizsgáló berendezés nemcsak a sík- és vákuumcsöves kollektorok tesztelésére alkalmas, hanem optimális lehet a koncentrátoros kollektorok vizsgálatára is. A szolár szimulátor alapvetően alkalmas kollektorok hőtechnikai tesztelésére. A hosszabb idejű biztonságos működéshez és a mérőrendszer mérési pontosságának megfelelő értéken tartásához a jelenlegi fejlesztési szinten még felügyelet és esetenként kézi beavatkozás is szükséges lehet. A berendezés teljes automatizálási szintjének eléréséhez és a mérési hibák minimálisra csökkentéséhez korrekciók, további fejlesztések szükségesek.

## *1. Introduction*

One of the most important parameters of solar collectors is the heat produced by a unit of area in a given period of time and the thermal efficiency available in the given weather conditions. The performance of solar collectors is characterised by an efficiency curve, which shows what fraction of the solar energy input can be utilised as heat energy (Farkas, 2003). The efficiency curve is defined with the help of a series of test which can be carried out in open air, on a sun tracking simulator or on a simulator equipped with an artificial light source placed indoors. According to the Hungarian standard MSZ EN 12975-2:2006 (E) the simulator we developed is suitable to carry out qualifying tests to measure heat energy as well as thermal exposure stress tests. Besides, our system makes it possible to carry out comparative analyses of different types of collectors under identical radiation conditions.

## *2. Materials and methods*

### *2.1. The structure of the solar simulator*

Our experimental system is a solar domestic water heating system using fluid for heat transfer, equipped with a circulation pump. It has a 150-litre insulated storage tank and it transfers the collected heat to the water with a built in heat exchanger. The system comes complete with built-in elements necessary for proper operation: circulation pump, expansion chamber, safety valve, temperature gauges and pressure meter) as well as the automatic electronic controller, and some of the instruments needed to carry out the tests (Fig. 1).

The solar collector unit to be tested is attached to the system with temporary binds, and a flexible pipe. There are two ways to place and fix the solar collector: it can be placed at a suitable angle on the sloping roof surface of the building facing to south, or it can be mounted on a frame similar to seen in Fig. 2. This allows two collector units to be fixed, which then can be tested in parallel as their orientation and angular position is the same. Besides it is possible to operate a solar collector unit with known conditions. For control measurements a vacuum flat collector was used.

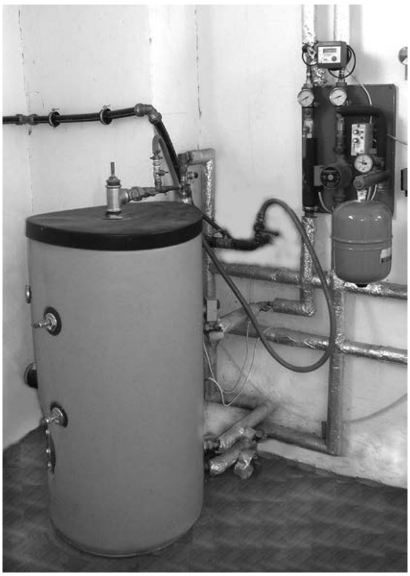


*Figure 1.* Components of the test equipment installed indoors at the Laboratory of University of Pannonia, Georgikon Faculty, Department of Agricultural Mechanization


*Figure 2.* Mounting frame of the simulator (University of Pannonia, Georgikon Faculty, Department of Agricultural Mechanization)

The vacuum necessary to operate the vacuum tube solar collectors is provided by a vacuum pump fixed on a mounting frame. The vacuum present in the system is displayed by a 10 mbar scale division vacuum meter. The continuous wind stream above the collector tubes necessary for heat performance tests is provided by an axial ventilator. The scaffolding has wheels to make the simulator unit mobile so when the tests are over, it can be pulled into a closed workshop. The support also has a fork attached to which can be turned round a vertical axis to allow the frame holding the collector to be tilted along a horizontal axis. The frame makes it possible to exactly orientate the collector tested and to set and fix the tilt angle.

The frame allows fixing of different size and type of collectors reaching up to the length of 1.7 m and the width of 1.2 m. The frame is suitable for on-by-one fixing the glass tubes of the vacuum tube collectors as well. The collector tubes fit into nests at the foot of the plinth board, while at their necks at the top they are fixed with thin plastic straps.

The vacuum tubes are attached to a common distributor or collector pipe with union nuts, so they can be changed simply and so after some short fitting it is possible to test a further evacuated tubular collector type.

The sun-tracking servo system is an electromechanical unit which is capable of making a tool turn in the direction of the sun that is keep a designated plan moving at a right angle (90 °) to the rays of the sun.

The necessary control loop consists of

- A sensor, which transforms any changes of the sun position or the momentary position of the moved object into electronic signals;
- A processing unit, which compares the signal characterising the different positions and according to the results of the comparison provides the elements generating the movement with electric energy;

Actuators which do the mechanical work with the help of the electronic energy, which in this case is a newel/screw shaft/screw spindle mechanism operated by a step motor. The rotation around the horizontal and the vertical axes is carried out by such a unit. (Fig. 3).

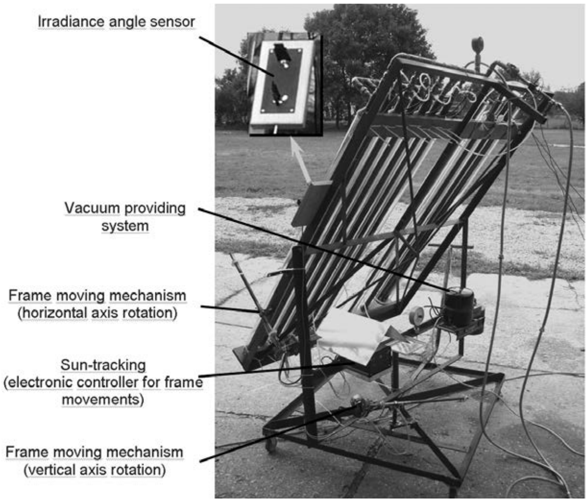
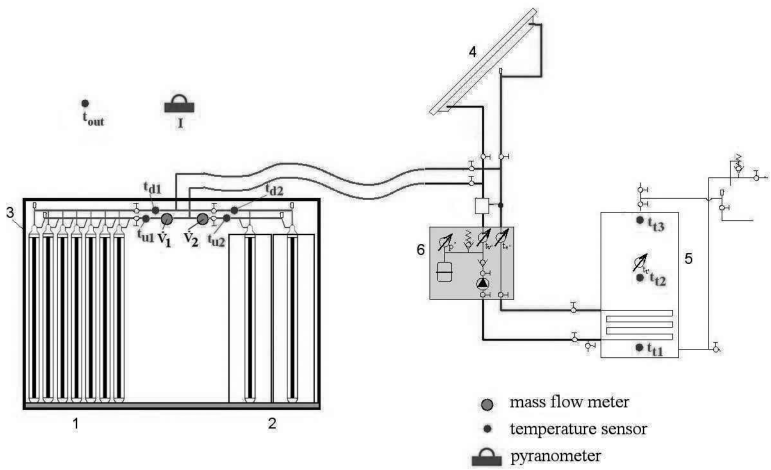



*Figure 3.* The mechanism moving the frame and the system providing the vacuum (University of Pannonia, Georgikon Faculty, Department of Agricultural Mechanization)

*2.2. The development of the measuring-controlling and data acquisition system*

The thermal-technology system we developed is suitable to carry out for stress tests of solar collector units, to measure collector efficiency, to measure and define thermal energy produced as well as to carry out comparative tests. The thermal energy produced by the collectors to be tested can be measured by temperature sensors installed inlet and outlet stream in the heat transfer fluid and volume flow rate signal device. During the tests it is essential that the environmental temperatures, global radiation intensity and storage tank temperatures should be measured (Fig. 4).




1.-2. – tested collectors; 3. – solar simulator; 4. - control-collector; 5. – hot water tank; 6. - solar device unit

*Figure 4.* Measuring points of the monitoring, controlling and data logging system

The output signals of the sensors are received by a 'Basic Stamp 2' micro computer and a software we developed transmits it to the data logger PC which collects the measured data in an Excel table and calculates the energetic characteristics of the collector for a certain point of time (Nagy, 2007). Global radiation can be measured with a Kipp & Zonen CM 21 type pyranometer. During the tests it is advisable to measure other weather parameters as well, e.g. wind speed, direction of wind, relative moisture content, air pressure, which can be registered with the help of a mobile meteorological station equipped with a digital data logger. The simulator equipped with the measuring devices can be seen in Fig. 5.

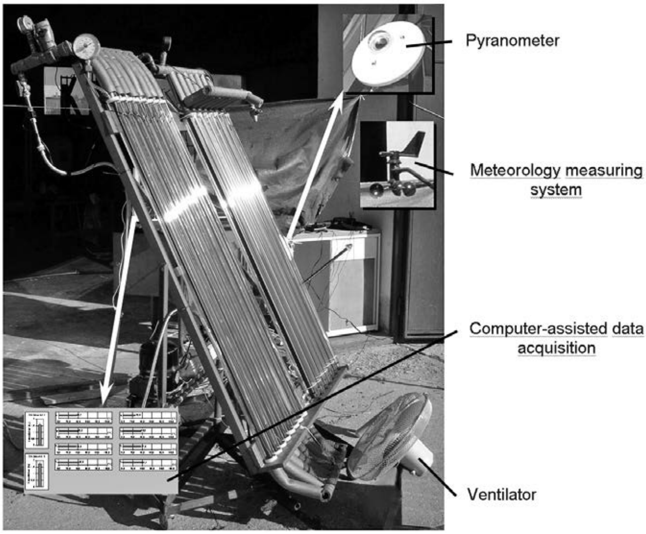



*Figure 5.* The simulator equipped with the test system (University of Pannonia, Georgikon Faculty, Department of Agricultural Mechanization)

*2.3. Measurements taken with the test equipment*

In our tests we examined and qualified vacuum tube collectors of three different types according to Chapter 5 of the standard MSZ EN 12975-2:2006 (E).

Tests were divided into two main groups: those of thermal and mechanic stress (exposure) and those of heat performance (Drück, 1997, Fischer, 1998). During the stress (exposure) tests we carried the collector units interior pressure tests, interior and exterior thermal shock tests, rain penetration tests, freeze resistance tests as well as drain-down tests and radiation exposure tests. In the thermal performance test we defined the output of the collectors and drew the efficiency-curves of the respective collectors (MSZ EN 12975-2:2006). The collectors were fixed on the solar simulator. The automatic sun tracking system ensured that the sun rays always fell onto the surfaces at a right angle (90 °) on. The hot or cold water circulation necessary for the respective tests was ensured by the water loop of our equipment. To test thermal performance we used the gauge system of our test equipment (Cseke, 2008).

## *3. Results*

The test carried out allowed not only the qualification of the collectors but they provided a lot of information about the suitable operation of the testing equipment as well. First we managed to put the mounting frame of the simulator to a test, which only went to show that the light profile steel structure was not able to steadily hold the mass of the collector tubes filled up with water. So it was necessary to fix the frame with further bracing. Besides this when collectors with different masses were being tested, it was necessary to apply extra weights to counterbalance the differences.

A precondition of collector performance testing is that there is a cloudless sky and even radiation. Under such conditions the automatic sun-tracking was able to follow the sun with an error of about 1% for both the sun height and the azimuth value, which was acceptable for our tests. However, under cloudy conditions, (at decreased solar radiation) in some cases the device was not working reliably, which necessitated manual intervention. As during the test periods, the sky was always bright, this did not cause any trouble in carrying out the tests. In long-term tests, however, (e.g. duration of several weeks) it would have been a great advantage if it had not been necessary to provide constant supervision of the system.

The driving mechanism of the sun-tracking system worked properly, the screw shaft mechanism has a slowing down so it is capable of generating even a small angle move the mounting frame, which is very advantageous from the point of view of exact/sensitive sun-tracking. However, it is not an ideal solution for the rotation around a vertical shaft as it is capable of covering a maximum of 120-140° rotation range, which would cause problems in the case of a whole-daylong test without supervision. The accuracy of the sensors of the measuring system is basically satisfactory. In case there is a satisfactory temperature increase of the fluid, then the DT measurement error is still acceptable. Should the temperature increase remain low, (e.g. because of low radiation), it would cause such a big error in the measurement of DT that it would make heat capacity measurements impossible.

To establish the collector efficiency under static conditions, it is an important requirement that the temperature of the water entering the collector should be kept constant. The accepted deviation is ±1K. In our testing equipment, we solved this problem by making the heat transfer fluid rotate in the heat exchange loop of the necessary length till it reached the constant temperature of the water in the tank. This simple cooling was – in most cases – enough to maintain constant temperature. In some cases, however, the fluctuation was bigger than acceptable thus the periods with no constant temperature may not be included on the evaluation, which would justify a control circle being built into the system.

## *4. Discussion*

It was experienced in the tests carried out so far that with the help of the equipment it was possible to significantly lengthen the testing periods in comparison with the fixed test benches. It is a further advantage that it is possible to adjust the angle difference between the collector and the direction of the solar radiation, so it was possible to quickly determine the correlation between the collector performance and the incidence/irradiation angle. The testing equipment is not only suitable to test flat and vacuum tube collectors but it might prove ideal to test concentrating collectors as well.

Basically the test equipment is suitable for thermal tests of collectors. Under present conditions, in order to achieve a longer term operation and to keep the accuracy of the system on an acceptable level, however, constant supervision and several instances of manual interventions are necessary. To reach the fully automated level and to further decrease the error, the following development and corrections are necessary.

- It is important to achieve that the automatic sun-tracking operates accurately independently of the radiation conditions. The problem is possible to solve with the installation of a light-intensity sensor and minor adjustment of the power circuit of the equipment.
- The transformation of the rotation mechanism of the simulator around the vertical axis, so that it can follow the full orbit of the sun. It is possible to solve with the installation of a worm drive.
- It is necessary to develop the control of the water temperature entering the collector. It necessitates the installation of an engine-operated mixing valve, which will mix the well warmed water coming from the outlet with a properly accurate regulation and the cold water coming from the tank and lets the mixture to the inlet side.

- To achieve a more accurate measurement of DT it is necessary to create a measuring circuit more accurate than the present one.
- Instead of the three different data logger units, (Basic Stamp, pyranometer, meteorological station) and the accompanying software, we would need a single data acquisition unit and one single software to go with it. It can be done with a more sophisticated Basic Stamp unit which is capable of receiving the data of the pyranometer and the meteorological station as well.
- In order to minimise heat losses, better insulation material quality should be used in the vicinity of the inlet stubs. The present polyfoam pipe insulation should be replaced with moulded polystyrene insulation elements.

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