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Nove rešitve za širšo uporabo sončne energije

New Solutions for a Wider Use of Solar Energy

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V prispevku navajamo rezultate razvoja izboljšanih in cenejših sončnih sistemov, ki so nastali v sodelovanju s slovenskimi proizvajalci sončne tehnike. Prikazane so karakteristike sončne strehe in analiza toplotnih in cenovnih prihrankov novo razvitih sončnih sistemov za pripravo tople vode v individualnih poslopjih.

The results of development of improved and cheaper solar systems achieved in cooperation with Slovenian producers of solar technique are listed in the paper. The characteristics of the solar roof and the analysis of heat and cost savings by the newly developed solar systems for the preparation of hot water in individual buildings are presented.

0 UVOD

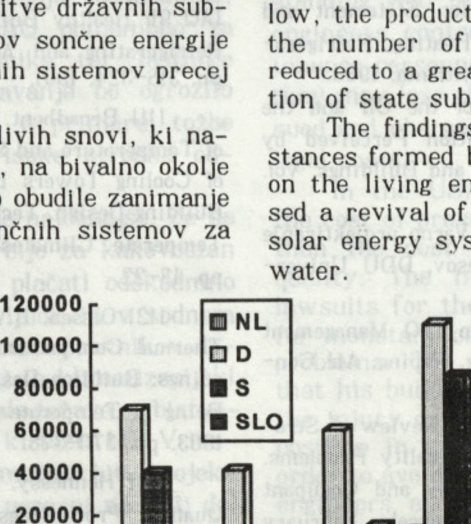
Konec sedemdesetih let je bila proizvodnja sprejemnikov sončne energije na vrhuncu. Razlog za to so bile napovedi o precejšnjem zvišanju cen fosilnih goriv. Ker pa so cene goriv ostale razmeroma nizke, sta se (zaradi ukinitve državnih subvencij) proizvodnja sprejemnikov sončne energije (SSE) in število novo instaliranih sistemov precej zmanjšali.

Ugotovitve o škodljivih vplivih snovi, ki nastajajo pri sežigu fosilnih goriv, na bivalno okolje pa so v mnogih državah ponovno obudile zanimanje za razvoj in širšo uporabo sončnih sistemov za pripravo tople vode.

0 INTRODUCTION

At the end of the seventies, the production of solar collectors was at its peak. The reasons for this were the predictions of a considerable rise in the prices of fossil fuels. However, since the prices of fossil fuels remained relatively low, the production of solar collectors (SC) and the number of newly installed systems was reduced to a great extent due to the discontinuation of state subsidies.

The findings on the harmful effects of substances formed by the combustion of fossil fuels on the living environment, however, have caused a revival of development and a wider use of solar energy systems for the preparation of hot water.



Sl. 1. *Letna proizvodnja SSE v m^2*

Fig. 1. *Annal production of SC in m^2*

Naraščanje proizvodnje SSE je jasno vidno tudi v začrtanih energetskih strategijah nekaterih držav. Tako so v Avstriji v zadnjih dveh letih instalirali 160 000 m^2 SSE, na Nizozemskem načrtujejo vgradnjo 1 200 000 sprejemnikov sončne energije do leta 2 010. V njihovih načrtih je tudi 40-odstotno znižanje cene sončnih sistemov do leta 1997 v primerjavi z letom 1991. V Sloveniji smo v načrtovanje preskrbe z energijo navedli, da pričakujemo do leta 2010 povečanje površine SSE od že vgrajenih 82 000 m^2 na 300 000 m^2.

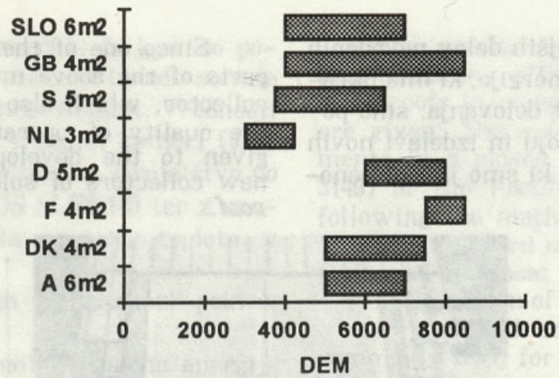
Po našem prepričanju je zastavljeni cilj mogoče doseči z naslednjimi ukrepi:

— izboljšanjem kakovosti sestavnih delov sončnih sistemov in njihovo medsebojno optimizacijo,

The increase in SC production is also evident from the planned energy strategies in some countries. Thus, in the last two years, 160,000 m^2 of SC were installed in Austria, and 1,200,000 m^2 of SC are planned to be installed in the Netherlands by 2010. A 40% reduction in prices of solar energy systems by 1997 in comparison to 1991 is also planned. The plan for energy supply in Slovenia includes an increase from the already installed SC area of 82,000 to 300,000 m^2 by the year 2010.

In the authors' opinion, the set objectives can be fulfilled through the following measures:

— improving of the quality of component parts of solar systems and their mutual optimization,



Sl. 2. *Cene sončnih sistemov v nekaterih evropskih državah*
Fig. 2. *The prices of solar systems in some European countries*

— znižanjem cene, ki je v sedanjem trenutku visoka (vendar primerljiva z evropskimi),

— povezovanjem slovenskih izdelovalcev sončne tehnike, kar bi omogočilo uresničitev zgoraj navedenih ukrepov,

— z državnimi in bančnimi olajšavami graditeljem ali proizvajalcem sončne tehnike.

Plod navedenih spoznanj je tudi projekt SOL 2010, ki ga predstavljamo v nadaljevanju in v katerem sodelujejo poleg Fakultete za strojništvo tudi FOTON, IMP-Klimat, Prema in KonTiki Solar.

1 PROJEKT SOL 2010

Namen projekta SOL 2010 je zagotoviti potrebno tehnološko opremo in ustrezne dejavnosti, da bi uvedli v Sloveniji aktivne sončne sisteme. V okviru projekta, ki poteka že drugo leto, so bile, s poudarkom na uvajanju domače tehnologije, opravljene naslednje naloge:

— razvoj kakovostnejšega sprejemnika sončne energije — *sončne strehe*,

— razvoj kompaktnega modula z dvoplaščnim hranilnikom toplote in pogonskimi elementi,

— razvoj preproste regulacijske enote,

— raziskave in razvoj integriranega sončnega sprejemnika in hranilnika,

— razvoj sistema brez dodatne energije, s sončno streho in dvoplaščnim hranilnikom toplote z integriranimi elementi za pravilno delovanje.

— reduction of their price which is high at the moment (but comparable to the prices in Western European countries).

— linking of Slovenian manufacturers of solar technology, which would enable the realization of the above mentioned measures,

— state and bank funding for installers or manufacturers of solar technology.

The SOL 2010 project, a joint cooperation of the Faculty of Mechanical Engineering, FOTON, IMP-Klimat, Prema and KonTiki Solar presented in the continuation is also a result of the listed findings.

1 SOL 2010 PROJECT

The purpose of the SOL 2010 project is to provide the necessary technological equipment and the corresponding activities in order to introduce active solar systems in Slovenia. The following tasks were carried out in the framework of the project, which has been going on for the past two years:

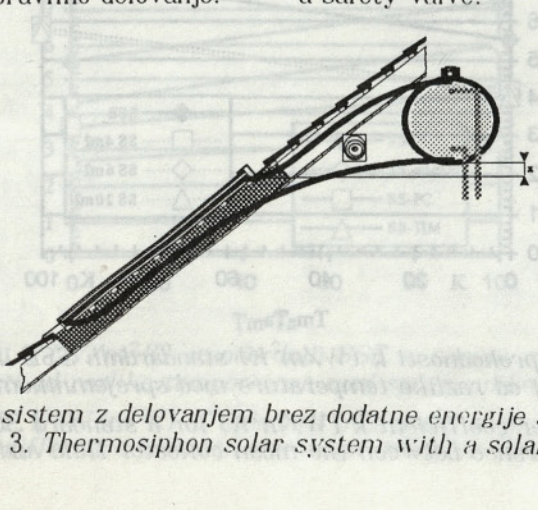
— development of a quality solar collector — *the solar roof*,

— development of a compact module with a double-walled heat storage and system operating unit,

— development of a simple control unit,

— research and development of an integrated collector storage,

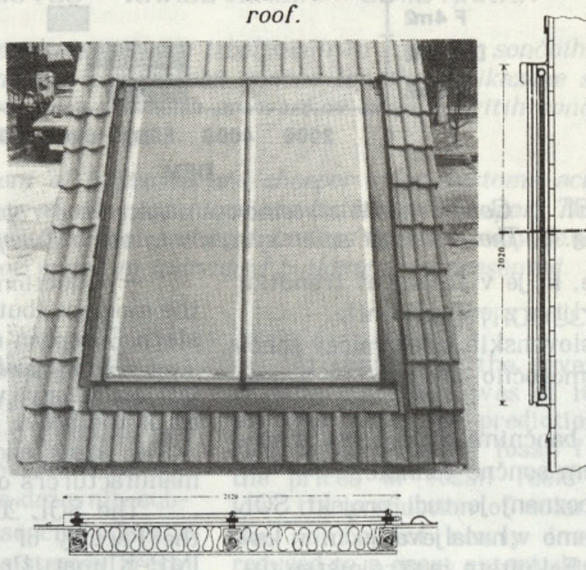
— development of a thermosiphon system, with a solar roof and a double-walled heat storage unit with integral expansion chamber and a safety valve.



Sl. 3. *Sončni sistem z delovanjem brez dodatne energije s sončno streho*
Fig. 3. *Thermosiphon solar system with a solar roof*

Ker je eden najpomembnejših delov navedenih sistemov sprejemnik sončne energije, ki ima hkrati tudi velik vpliv na kakovost delovanja, smo posebno pozornost posvetili razvoju in izdelavi novih sprejemnikov sončne energije, ki smo jih poimenovali *sončna streha*.

Since one of the most important component parts of the above mentioned systems is a solar collector, which also exerts a large influence on the quality of operation, special attention was given to the development and manufacture of new collectors of solar energy, named *the solar roof*.



Sl. 4. *Sončna streha*
Fig. 4. *The solar roof*

2 SPREJEMNIK SONČNE ENERGIJE — SONČNA STREHA

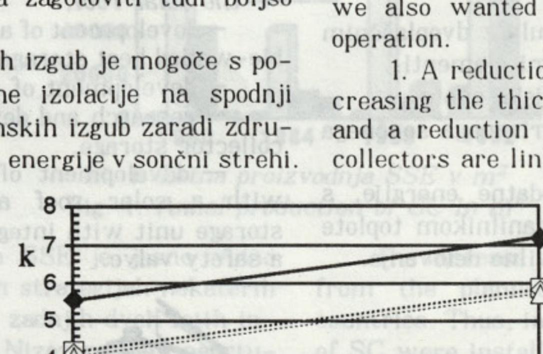
Sončno streho sestavlja poljubno število sprejemnikov sončne energije, ki so povezani v celoto in vgrajeni v streho stavbe. Ker so tudi vsi vezni priključki izvedeni znotraj sončne strehe, je taka zasnova tudi dobra estetska rešitev. Vendar pa smo želeli poleg lepšega videza zagotoviti tudi boljšo učinkovitost delovanja.

1. Zmanjšanje toplotnih izgub je mogoče s povečanjem debeline toplotne izolacije na spodnji strani in zmanjšanju stranskih izgub zaradi združenih sprejemnikov sončne energije v sončni strehi.

2 SOLAR COLLECTOR — THE SOLAR ROOF

The solar roof consists of a random number of solar energy collectors linked into a whole and installed on the roof of a building. Since all connecting tubes are inside the solar roof, such a design also represents a good aesthetic solution. However, besides a pleasant appearance, we also wanted to assure better efficiency of operation.

1. A reduction of heat loss is possible by increasing the thickness of insulation on the back and a reduction of side loss since a number of collectors are linked in the solar roof.



Sl. 5. *Toplotne prehodnosti k (W/m^{2}K) standardnih SSE in sončne strehe v odvisnosti od razlike temperature med sprejemnikom in okoljem*
Fig. 5. *Heat transfer coefficient k (W/m^{2}K) for a standard SC and the solar roof in relation to the difference between the mean collector fluid and ambient temperatures*

Rezultati so prikazani na sliki 5, kjer so podane toplotne prehodnosti različnih izvedb sončne strehe v primerjavi s sedanjimi sistemi. Vrednosti so bile dobljene s preizkusi v zaprti komori (JUS M.E6.080, ISO 3149) na Fakulteti za strojništvo po metodologiji, predpisani v JUS M.F5.110 ter z uporabo matematičnega modela prenosa toplote v SSE [1].

2. Zmanjšanje toplotnih izgub skozi pokrov SSE.

Pri standardnih sprejemnikih sončne energije uporabljamo za prosojen pokrov v večini primerov steklo. Poleg nekaterih odličnih lastnosti je glavna pomanjkljivost stekla velika toplotna prehodnost ($k = 5$ do $6\ W/m^2K$). Možnosti za zmanjšanje teh izgub smo analizirali na dveh prosojnih izolacijskih materialih, uporabili smo:

— polikarbonatno satovje PC (debeline 4,5 mm, $k = 2,7\ W/m^2K$); satovje je stabilizirano z zaščitnim nanosom in dodatnim nanosom na notranji strani, ki odbija toplotno sevanje (učinek tople grede) in

— kapilarno prosojno izolacijo - TIM, ki smo jo zlepili na steklo (debeline 8 cm, $\lambda_{ekv} = 1,2\ W/m^2K$). Ob tem smo razvili postopek lepljenja kapilarne izolacije na steklo, saj je tesen stik med obema slojema nujen za preprečitev konvektivnih zračnih tokov znotraj SSE. Vrednosti toplotne prehodnosti, določene po že navedeni metodologiji, so razvidne na sliki 5.

Iz diagrama na sliki 6 je razvidno, da vgradnja TIM zagotavlja najnižje toplotne prehodnosti sončne strehe in s tem tudi najvišjo učinkovitost. Tudi vgradnja kritine PC ima prednost pred stekleno kritino.

2. 1 Primerjava učinkovitosti različnih izvedb sončne strehe

Zaradi različnih optičnih lastnosti kritin, ki so močno odvisne tudi od vpadnega kota sončnega sevanja, poznavanje toplotne prehodnosti še ni zadostno za primerjavo in napoved delovanja sončnih

The results are shown in Figure 5, where heat transfer coefficients for different variants of solar roofs in comparison with standard systems are given. The values were obtained by experiments in a closed chamber (JUS M.E6.080, ISO 3149) at the Faculty of Mechanical Engineering following the methodology prescribed in the JUS M.F5.110 standard and with the use of a mathematical model of heat transfer in a SC [1].

2. Reduction of heat loss through the SC cover.

In standard solar collectors, glass is most commonly used for the transparent cover. In addition to some excellent properties, the main shortcoming of glass is high heat transfer coefficient ($k = 5$ to $6\ W/m^2K$). The possibility of reduction of these losses were analyzed for two transparent insulation materials:

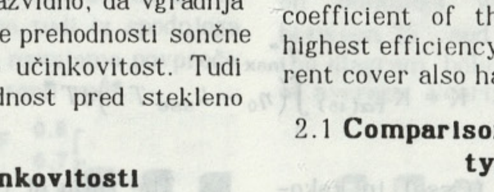
— polycarbonate honeycomb PC (of 4.5 mm thickness, $k = 2.7\ W/m^2K$); the honeycomb is protected from UV rays with a protective layer and with additional layer on the inner side for reflecting thermal radiation(greenhouse effect) and

— capillary transparent insulation material - TIM, which was glued on glass (of 8 cm thickness, $\lambda_{eq} = 1.2\ W/m^2K$). A procedure for coating of glass with capillary insulation was developed, since close contact between both layers is essential to protect convective heat transfer inside the SC. The values of heat transfer coefficient, determined using the mentioned methodology, are shown in Figure 5.

In the diagram in Figure 6 shows that installation of TIM ensures the lowest heat transfer coefficient of the solar roof and with it the highest efficiency. The installation of PC transparent cover also has an advantage over glass cover.

2.1 Comparison of efficiencies of different types of solar roof

Due to different optical properties of the transparent cover, which depend to a large extent on the incidence angle of solar radiation, the knowledge of heat transfer coefficient is still not sufficient for the comparison and prediction of operation of solar systems. The efficiencies of

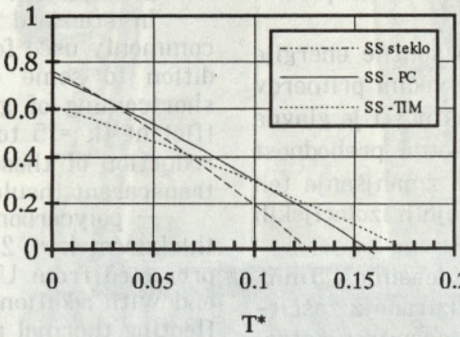


Sl. 6. *Toplotne prehodnosti k (W/m^2K) standardnih SSE in sončne strehe z različnimi kritinami v odvisnosti od razlike temperature med sprejemnikom in okoljem*

Fig. 6. *Thermal transfer coeff. k (W/m^2K) of standard SCs and a solar roof with different transparent covers in relation to the difference between the mean collector fluid and ambient temperatures*

sistemov. Zato smo na zunanjem preizkuševališču po metodi, ki je predpisana v JUS M.F5.110, določili tudi učinkovitosti različnih izvedb sončne strehe. Rezultate navajamo v diagramu učinkovitosti v odvisnosti od srednje temperature medija v SSE (Tm), temperature okolice (Ta) in jakosti sončnega sevanja (G). Te vrednosti združimo v reducirano temperaturo $T^* = (Tm - Ta)/G$.

different types of solar roof were therefore determined on a test-field following the method prescribed in the JUS M.F5.110 standard. The results are shown in the diagram showing efficiency in relation to the mean temperature of the collector fluid in the SC (Tm), ambient temperature (Ta) and intensity of solar radiation (G) - these values are combined in the ratio $T^* = (Tm - Ta)/G$.



Sl. 7. *Učinkovitost sončne strehe z različnimi prosojnimi pokrovi*
Fig. 7. *Efficiency of the solar roof with different transparent covers*

Kakovost različnih SSE lahko neposredno primerjamo s številom K — kakovostjo sončne strehe. Ta je definirana z izrazom:

The quality of different SC can be directly compared using the K value of the solar roof. This is defined by:

$$K = \frac{\eta_C \, T^*_{max}}{2}$$

$$K = K_{\tau\alpha(45)} \int_0^{T^*_{max}} \left(\eta_0 - k_{sse} \, T^*\right) dT^*$$

Razmerje med ceno SSE (Csse) in kakovostjo SSE (K) da dejansko kakovost, ki jo določimo z izrazom:

The ratio of the price of SC (Csse) and the quality of the SC (K) is the effective quality, determined by the expression:

$$K_{sse,e} = \frac{C_{sse}}{K}$$

Za navedene izvedbe sončne strehe (SS) so zgoraj navedene vrednosti naslednje:

The above mentioned values for the listed types of solar roof (SS) are the following:

Preglednica 1: *Primerjava ekonomskih kriterijev za različne izvedbe sončne strehe*
Table 1: *Comparison of economic criteria for different types of solar roof*

	C_{sse}	K	$K_{sse,e}$
SS — steklo	550	0,051	10 842
SS — PC	510	0,054	9 473
SS — TIM	600	0,052	11 599

Iz rezultatov, navedenih v zgornji preglednici, je razvidno, da je kakovost K najvišja pri sončni strehi s kritino PC. Kakovost sončne strehe s TIM

The results presented in the table above show that the quality K is highest for the solar roof with PC transparent cover. The quality of the solar roof je sicer večja kakor pri steklu vendar je širše uvajanje te rešitve povezano z visokimi stagnacijskimi temperaturami, ki jih doseže absorber. Stagnacijske temperature za najkvalitetnejše na trgu dosegljive TIM namreč znašajo do 170 °C. S preizkusom pa smo ugotovili, da je bila ta temperatura dosežena ob sončnem vremenu (G = 900 W/m²) že pri temperaturi okolice 10 °C. Zato menimo, da je vgradnja TIM primerna le pri integriranih sprejemnikih sončne energije z vgrajenim hranilnikom, ki se, zaradi akumulacije toplote, precej manj segrejejo.

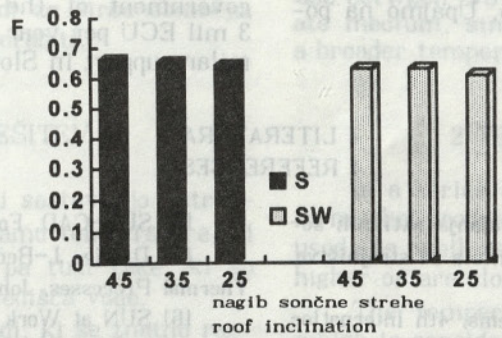
with TIM is higher than for a roof with glass, but a wider introduction of this solution is associated with high stagnation temperatures reached in the absorber plate. The stagnation temperature for TIM of the highest quality available on the market is 170 °C. It was found with this experiment that this temperature was achieved in sunny weather (G = 900 W/m²) at an ambient temperature of 10 °C. It is therefore our opinion that installation of TIM is suitable only for integrated collector storage, which due to heat accumulation heat up considerably less.

2.2 Toplotni prihranki pri pripravi tople vode s sončno streho

Toplotne dobitke solarnega sistema s sončno streho navajamo kot faktorje pokritja potreb po topli vodi za enodružinsko stanovanje. Za analizo smo uporabili programsko opremo SUN-CAD [5], ki temelji na metodi f-chart [6]. Drugi parametri so naslednji : dnevna poraba tople vode s temperaturo 45 °C je 150 litrov/dan, površina sončne strehe 6 m², prostornina dvoplaščnega hranilnika toplote 180 litrov. Analizirali smo tudi pomanjkljivost sončne strehe, ker sta naklon in usmeritev odvisna od že izvedene strehe in zato optimalna namestitev ni mogoča. Vendar rezultati kažejo, da se toplotni dobitki pri vgradnji sončne strehe na stavbe z običajnimi nagibi streh med 25° do 45° le malo razlikujejo. To je razvidno tudi iz spodnjega diagrama na sliki 8, v katerem navajamo povprečna celoletna pokritja potreb po topli vodi.

2.2 Heat savings in the preparation of warm water with the solar roof

Heat gains to the solar systems with the solar roof are listed as factors covering the needs for warm water for one-family flat. SUN-CAD software [5] based on the f-chart method [6] was used for the analysis. Other parameters are the following: daily consumption of warm water at a temperature of 45 °C is 150 litres/day, the area of the solar roof is 6 m², the volume of double-walled heat storage is 180 litres. The shortcomings of the solar roof were also analyzed, since its inclination and orientation depend on the existing roof, so that optimal installation is rendered impossible. However, simulations show that heat gains differ very little for installation of solar roofs on buildings with normal roof inclinations between 25° and 45°. This is also evident from the diagram below, Figure 8, where the values of average yearly solar factors are given.



Sl. 8. *Celoletna pokritja potreb za južno in jugozahodno usmerjeno sončno streho*
Fig. 8. *Average yearly consumption coverage for a south and southwest oriented solar roof*

2.3 Cenovna analiza sistemov, razvitih v okviru projekta SOL 2010

Sistem sončna streha je zasnovan v sistemu »kit«. To pomeni, da kupec dobi v kompletu vse potrebne elemente, kar omogoča tudi individualno gradnjo. Tudi to dejstvo omogoča, poleg prihranka pri nosilni konstrukciji sprejemnikov sončne energije in kritini, znižanje cene. Tudi drugi elementi sistema, predvsem hranilnik in pogonski elementi

2.3 Price analysis of systems developed within the SOL 2010 project

The solar roof is designed in a Do-It-Yourself system. This means that the customer is provided with all necessary elements in a kit, which also enables individual installation. In addition to the savings on structure of the solar collectors and the transparent cover, this also enables the reduction of the price. Other elements, above all the heat storage and the operation unit are designed so zasnovani tako, da so čim cenejši. Kljub temu, da so vgrajeni materiali zelo kakovostni, nam je uspelo ceno sistema znižati. Tržne vrednosti so naslednje:

in such a way that they are as cheap as possible. Even though the built-in materials are of very high quality, we succeeded in reducing the price of the system. The market values are the following:

Preglednica 2: *Cenik sončnih streh in sistemov, razvitih v okviru projekta SOL 2 010*
Table 2: *Price list of solar roofs and systems developed within the SL 2010 project*

SS 4 m²		950
SS 6 m²		1 350
SS 4 m² termosifon (thermosiphon)	V_{HT} = 150 l	2 000
SS 4 m² s črpalko (with pump)	V_{TH} = 150 l	2 300
SS 6 m² s črpalko (with pump)	V_{TH} = 200 l	2 700

Cene so navedene v DEM zaradi lažje primerjave z navedenimi v uvodu. Kljub temu, da so razmeroma visoke, pa so vsaj za 40 odstotkov nižje kakor pri standardno zasnovanih sončnih sistemih.

For easier comparison with the prices stated in the introduction, the prices are stated in DEM. Even though they are relatively high, they are at least by 40% lower than the prices for solar systems of standard design.

3 SKLEP

Iz navedenih rezultatov lahko povzamemo, da je mogoče izdelati cenejši sončni sistem ter kljub temu izboljšati njegovo kakovost.

Dodatno izboljšanje kakovosti pa predvidevamo z uporabo absorberjev s selektivnimi nanosi. Nadaljnje uvajanje sončnih sistemov bo mogoče le ob:
— vključitvi socialnih stroškov v ceno goriv, kar je malo verjetno ali
— množičnem uvajanju aktivnih sončnih sistemov, ki bo v skladu z načrti energetske preskrbe finančno podprto.

Nizozemska vlada je že v omenjenem projektu temu namenila 3 mio ECU letno. Upajmo na podobno podporo tudi v Sloveniji.

3 CONCLUSION

It can be concluded from the listed results that it is possible to manufacture a cheaper solar system and at the same time improve its quality.

The use of absorbers with selective covers is expected to provide an additional improvement of quality. Further introduction of solar systems will, however, be possible only by:
— including social costs into the price of fuels, which is hardly probable, or
— mass introduction of active solar systems, which will be financially in concordance with energy supply plans.

As part of the above mentioned project, the government of the Netherlands has earmarked 3 mil ECU per year for this. Let us hope for similar support in Slovenia, too.

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