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Design and Manufacturing of Thermosyphon Solar Water Heater by Using Available Locally Materials in Nsanke village

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Abstract

The weather conditions of Nsanke village starting from April till October emphasize the need for judicious utilization of warm water. We designed, constructed and tested a Solar Water Heater based on Thermosyphon principle in Nsanke village using locally available materials. Solar energy is received by two flat-plate collectors of $1.68 m^2$ each, consisting of absorber plate carrying copper tubes and placed in an insulated casing with a transparent glass cover of $4 mm$ thickness. The collectors are connected in series and are assumed to operate on the same efficiency. The resultant collector is connected to a storage tank, which is an association of two barrel nested all in all and separated with an insulator. The radiation emitted by the absorber plate cannot escape through the glass, thus increasing its temperature. The system's performance evaluation has shown that it can heat water from $23^\circ C$ to at least $51^\circ C$ at sunny day. The water heated flows into a storage tank through Thermosyphon principle. This Solar Water Heating system which uses Thermosyphon principle and, which is thereby called for simplicity Thermosyphon Solar Water Heater (TSWH), finds useful application and acts as a renewable energy resource in Nsanke village and other localities where there is abundant and consistent sunlight.

Keywords: Weather conditions, Warm water, Thermosyphon principle, Solar Water Heater, Nsanke village.

1. Introduction

Nowadays, air pollution management [1, 2] and energy supply [3, 4] have become major issues. Number of policies and campaigns aimed not only at reducing the volume of harmful emission release into atmosphere, but also to provide strategy on mitigating high among of energy demand have been initiated [3, 5, 6]. Globally, those programs which were launched by many countries were focusing particularly on strategy for energy consumption, fuel diversification, and the use of renewable energy, paying attention on renewable energy technologies such as and not limited to solar photovoltaic, wind turbines, geothermal, biomass, water reservoir, energy supply, wave generators solar thermal [7, 8, 9-12]. Nevertheless, the strategies implemented for using these renewable energy technologies and devices, differ between industrialized nations and developing countries. Therefore, while the former achieved significant energy savings through demand management, developing countries still focus their strategies on increasing the domestic energy supply [8].

In Cameroon, like in many other African countries, the production and use of renewable energy have been found as the main solution to be adopted in order to improve the current energy crisis [6]. Among various solutions which have been proposed, authors of Ref.[5] focus on four primary mitigation strategy components including (i) carbon efficiency, (2i) energy efficiency of technology, (3i) systemic and infrastructure efficiency and (4i) service demand reduction. While Abanda et al.(2014) [13] designed and implemented an improved mud-brick cook stove, Tidze et al.(2016) [14], in their research study based on dynamics of household energy and cooking stoves in Maroua, Far North Region of Cameroon, suggested the usage of energy efficient stoves as sustainable cooking energy alternative source. Similar research work, concerning the development of renewable energy technologies in Cameroon in order to address energy demand have been carried by several authors [15, 16, 17, 18, 19].

In the same line, we designed and manufactured a TSWH which uses available locally materials in Nsanke village. Our motivation for designing such a solar system comes to the fact that, in Nsanke village as well as in many villages in Cameroon (in particular local communities in West, South-West and North-West Divisions), the cost of essential commodities is on the high side. The aim of the present research study is to look for the possibilities alternatives including the development of renewable energy technologies [3] and devices more reliable and less expensive to sustain inhabitant's daily activities. We recall to readers that the present research work is the continuity of the Central African Sustainable

Cities Initiative (CASCI) launched in Nsanke village by a research group of the African Scientific Association for Innovative and Entrepreneurship (ASAIE) in partnership with *Laboratoire Energetique Carnot (LEC)*, Promotion Centre of Research for Technological Advancement and Sustainable Development (PCR-TQSD) and *PROSOFOR AFRIQUE* aiming to fight against poverty and rural exodus and stimulate the local economy in Central Africa Region.

The rest of the paper is organized as follows: in section 2 we present the material used and methodology choose in order to attempt the objectives. In section 3, results are presented. The above results are discussed in section 4. The paper ends in section 5 with a summarized conclusion.

2. Materials and methodology

2.1. Materials

Various materials have been used in order to achieve the aim followed in this study. These materials have been selected depending on some keys factors. These include the economic considerations, the availability of the material in the local market, the extensibility of the material in construction, ease in maintenance and also physical property of the material such as thermal conductivity and resistivity to cite only these few. Those materials are depicted in Table I which presents each material and its use in the present research work.

Other important materials used in this study constitute of global positioning system (GPS) for surveying in order to map the location of the study area and a camera. In addition, for a perfect design of the model TSWH, interviews where carried to collect basic data in the guest houses. The target groups selected for interview consist of occupants of the guest house. The phase consisted on the interview has been essentially based on a systemic gait. Our questions, either oral or mentioned in the questionnaires, allowed us to get information concerning essentially the volume of hot water used by every occupant a day and the average number occupants which can be meeting in the guest house at any time.

Table I. various materials used for design and construction of the model TSWH.

Materials	Usage
Nails	To joint various part of our model TSWH
Hammer	

Gate	These materials were used for connecting pipe from storage tank to the collector header and riser
Faucet	
Compression pipes	
Solarimeter	Type of measuring component used to measure combined direct and diffuse solar radiation
Thermal probe	Devices, designed to measure temperature within and out of the storage tank and collectors
Multimeter	
Hot water tank or storage tank	A hot water tank or storage tank was constructed from two barrels of 100l and 250l respectively. The first one, that is the one with the volume of 100l is shifted in the largest one; the interval between those them been filling with chip.
Chip	Chip is used as a heat insulator to prevent heat loss.

2.2. Methodology

In order to assess data, we follow a qualitative approach consistent on literature review, field investigation and data analysis. In the former, some data were downloaded online from Google page (<https://www.google.com/>). These information's allow getting some basic knowledge concerning TSWH such as various assembly elements and their characteristics. In particular, the collected information permitted us to get ideas base on previous research studies focused on TSWH. On the field, both detail field surveys and interviews were carried out using Global Positioning System (GPS) and questionnaires respectively, in order to map the location of Guest House in one hand and, get information concerning essentially the volume of hot water used by every occupant a day and the average number occupants which can be meeting in the Guest House at any time in other hand. The step-by-step method employed for constructing the TSWH is well presented in Table II.

Table II: Step-by-step method employed for constructing the TSWH.

Step N ^o	Designation	Activities involved
1	Choice of the technology	<ul style="list-style-type: none"> - Choosing a type of collector - Choosing a type of boiler
2	Measure of irradiation of Nsanke village	<ul style="list-style-type: none"> - Choice of the appropriate software : Rescreen - Measurement of irradiation in Nsanke

		village
2	Evaluation of warm water needs in the Guest House	- Evaluation of number of occupants and their need of warm water (in letters)
	Choice of materials for TSWH manufacturing	- Glazing, - Heat exchanger, - Absorber and its cover, - Insulations, - Frame, - Constituents elements of the storage tank.
4	Sizing of collector's elements (Figure 1)	- Absorber's area, - Insulator 's tickness, - Sizing of the frame,
	Sizing of storage tank (Figure 2)	- Storage volume, - Insulator 's tickness.
	TSWH system assembly (Figure 3)	- Storage tank - Collector
5	TSWH device installation	- Choice of the site - Installation of the system
6	Performance evaluation of the TSWH manufactured	- Measurement of the temperature at the entrance and at the exit point of the collector as well as those at the exit point of the storage tank by means of thermocouple.

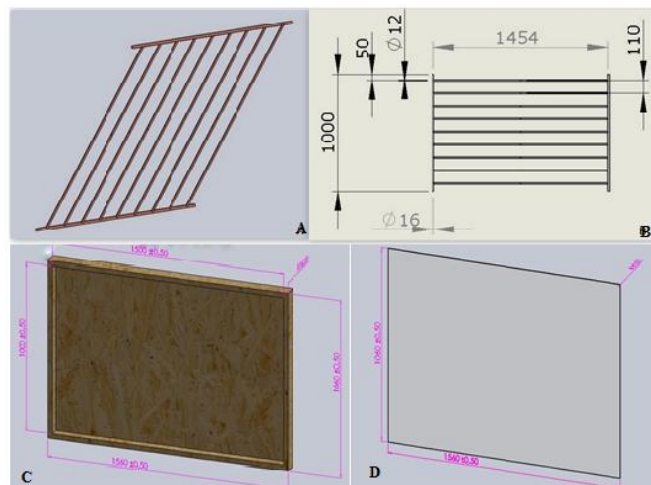


Figure 1: Sizing of the collector's elements. (A and B) exchangers, (C) frame and (D) glazing.

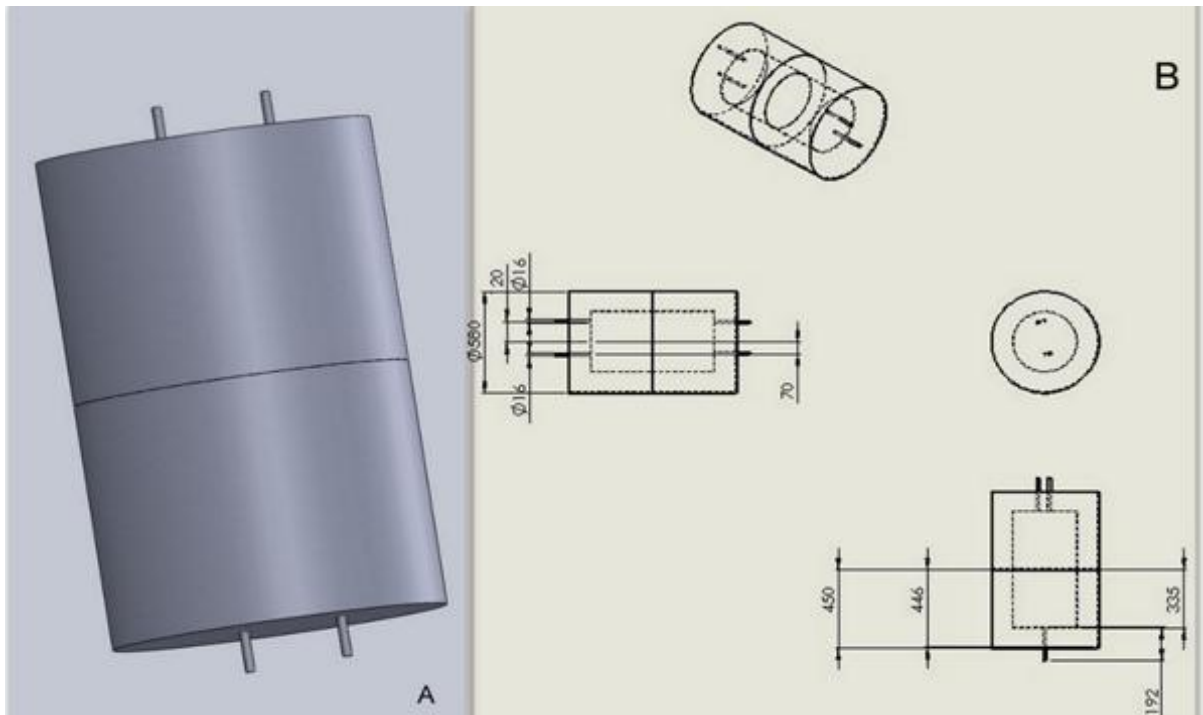


Figure 2: Storage tank design.

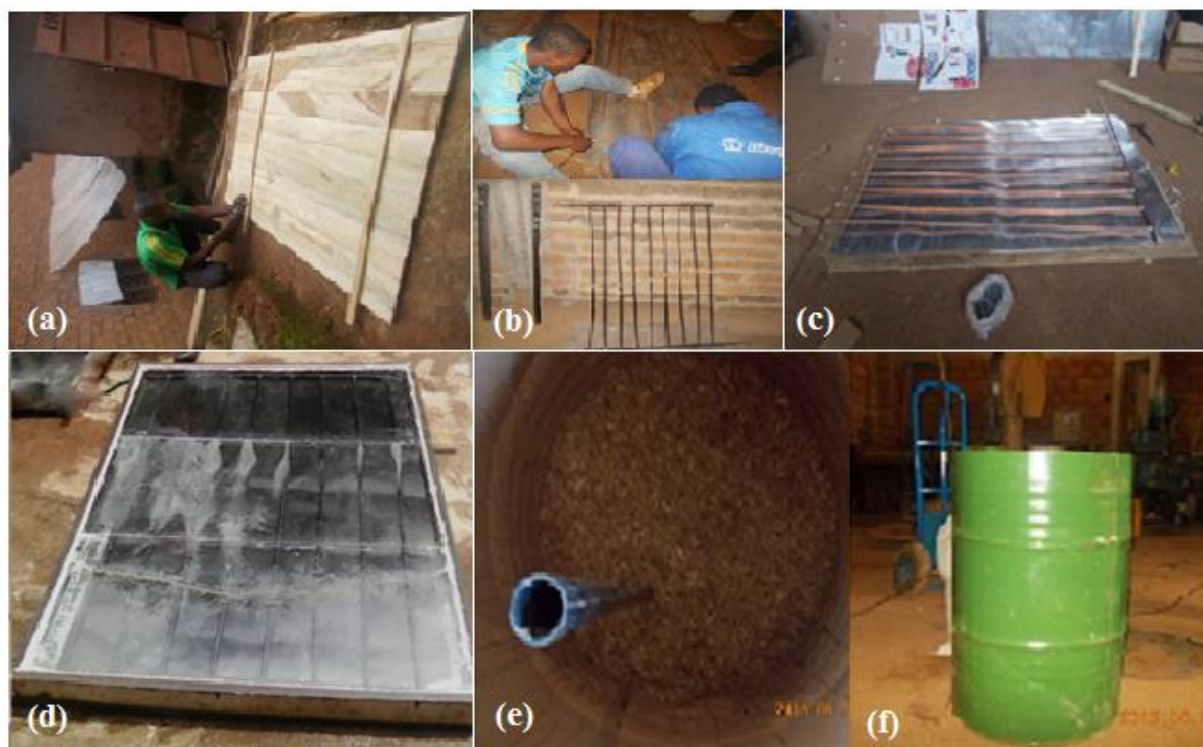


Figure 3: Final TSWH system assembly. (a) manufacturing of the collector, (b) manufacturing of the exchanger, (c and d) manufacturing of the absorber, (e and f) manufacturing of the storage tank.

3. Results

3.1. Occupation of the Guest House and need of hot water

Data investigation and analysis based on the number of occupants and their requirement in warm or hot water has leads to the results in Figure 4 and Figure 5 respectively.

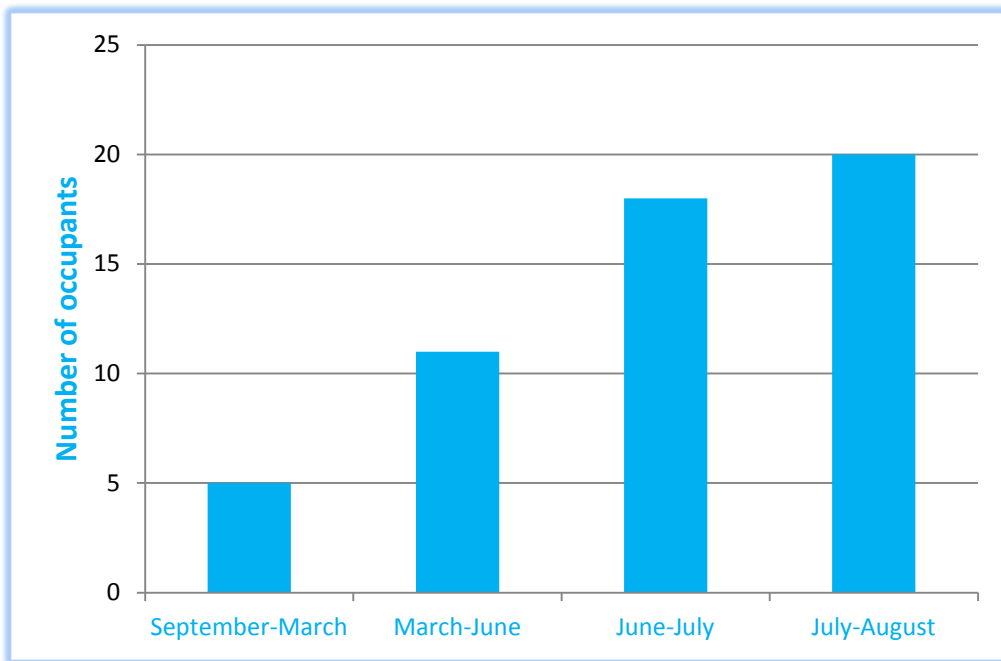


Figure 4. Graphical representation of number of occupants versus period in the year

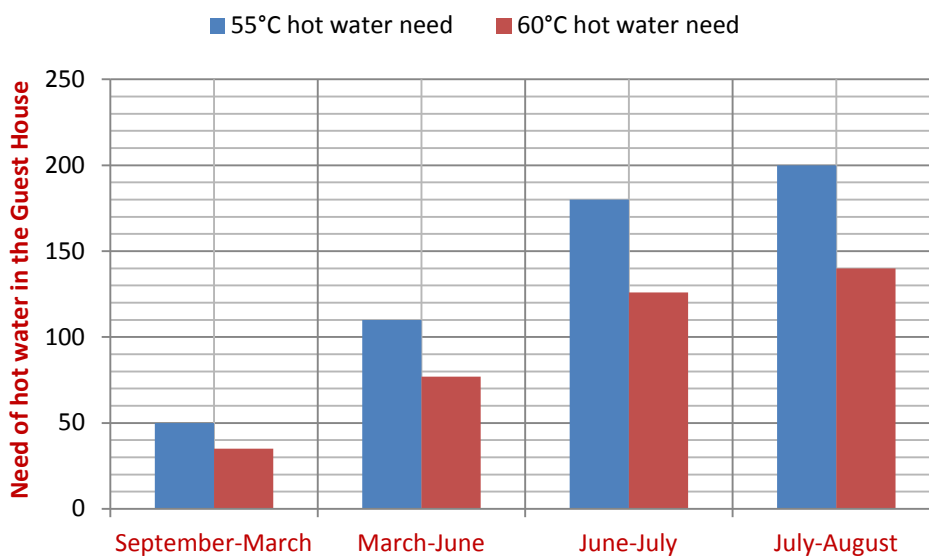


Figure 5. Graphical representation of the needs of water for occupants of the Guest House versus period in the Year

3.2. Description of the Thermosyphon Solar Water Heater system manufactured

Following each step of design and manufacturing previously, we obtained the final TSWH system given in Figure 6 below. The system is constituted of a 100 liter metallic tank nested in that of 250 liters. The system has the following components: solar thermal collectors, water storage tanks, connecting pipelines, and the water to be heated and circulated within the solar water heating system. The source of heat is used by heat falling on the collector's surface which generates the heat source. The sun rays fall directly over the collectors which result to the heating of tubes which constitute the collector. The water then is passed to flow through the heated tubes which result in changes in temperature of the water. Thus the water get heated up and the temperature starts increases.



Figure 5. Final TSWH system designed, manufactured and installed.

3.3. Physical characteristics of the TSWH manufactured

Physical characteristics of the TSWH manufactured are given in Table III.

Table III. Design results for TSWH manufacturing.

Items	Results or assumptions	
Guest House	Individual hot water need (l/day)	7
	Needs (KWh/day) evaluated from <i>eq.1</i>	2.25972 KWh/day
Sensor	N° of glass covers	1
	Thickness of glass cover	4 mm
	Absorber's material	Aluminium
	Material of the serpentine	Copper
	Serpentine's dimensions	10 mm / 12 mm 10
	Material of the sensing insulator	Cardboard ($\lambda = 0.048 W m^{-1} \circ C^{-1}$)
	Thickness of the sensor's insulator	$e = 2.64 cm$
	Cock material	Firewood
	Thickness of cock material	$e = 30 mm$
	Absorber's area	$S = 2.85 m^2$
	Fame's dimensions	Length: $L = 160 cm$; Width: $l = 105 cm$; Thickness or elevation: $h = 9 cm$
	Tubes spacing	100 mm
	Storage tank	Material of the storage tank
N° of tanks used		2 (100l, 250l). The first one (100l) is nested in the other (250l)
Material of the storage tank insulator		Shaving
Thickness of the storage tank insulator (the interval between 100l barrel and 250l barrel nested all in all)		$e = 11 cm$
Water inlet temperature		23 °C

3.4. Performance evaluation of the TSWH manufactured

After having designed and manufactured the TSWH, several tests have been made in order to evaluate the performance of the system. Doing it, we measured the temperature at the entrance and at the exit point of the sensor as well as those at the exit point of the storage tank by means of thermocouple. These measures have been investigated on four different days, starting Wednesday 1st July 2022 to Saturday 4th July 2022, in order to appreciate the result, since the sunniness is a function of day irradiation. The measures have been made different days at different times. The results obtained are shown in Table IV. The result shows that sensor output temperatures increase with sunshine, sky clarity and sunshine time.

Table IV: TSWH performance evaluation results.

Day	Time (h)	Irradiance (W/m ²)	Sensor		Storage tank	Efficiency (%)
			Inlet Temp (°C)	Outlet Temp (°C)	Outlet Temp (°C)	
Wednesday	10:00	240	18	27	25	36.2
	11:00	260	18.5	30	28	42.7
	12:00	283	18.7	34	32	52.3
	13:00	300	19	37	35	58.0
	14:00	333	20	40	37.5	58.1
Thursday	13:00	390	18	37	35	47.1
	14:00	384	19	40	38	52.9
	15:00	440	20	45	41	54.9
	16:00	241	22	38	39	64.2
	17:00	230	22	34	35	50.4
Friday	10:00	206	18	33	33	50.7
	11:00	220	19	35	36	50.6
	12:00	306	19	41	38	51.0
Saturday	11:30	300	18	39	38	62.7
	12:30	500	19	48	39	63.8
	13:30	600	19	51	40	65.3

Saturday	14:30	374	19	43	40	63.5
	15:30	380	20	43	40	59.9
	16:30	400	21	49	42	69.3
	17:00	375	21	43	42	58.1

4. Discussions

The overall results presented in Table IV clearly indicate that the irradiance levels and the output temperature (both for the sensor and the storage tank) are closely related. This result is in agreement with the observation of Ubani and Adejare in Nigeria (2022) [20]. For the entire days of testing during the earlier raining season (July), an outlet temperature of 51°C was the highest temperature observed at the exit point of the sensor and 42°C at the exit point of the storage tank. The outlet temperature obtained through our system for both the sensor and the storage tank was in the highest value compare to that obtained by Adejare in Nigeria (2022) [20]. The result is not surprising since the authors (Ubani and Adejare (2022) [20]) perform experimentation during the late raining season while we carried our test in the early raining season. In fact, they authors mentioned the fact that the Solar Water Heater performs well in dry season than in raining season. Thus, for the entire days of testing during the dry season, the maximum outlet temperature observed by the authors of Ref.[20] was 75°C.

In general, as likely as the results of Ogie et al. (2013) [21], maximum fluid (water) output temperature at both the exit point of the sensor and the storage tank was obtained between noon and afternoon. The Insolation increased from a low value at 10:00 A.M. got to a peak between noon and 3:00 P.M. and then fell back to a low value. Nomatter the output temperature of the water at the exit point of the storage tank is lower than the one obtained by Ubani and Adejare (2022) [20] (44.30°C), we cannot explain such a result in regard of the collector's area given that using a larger collector area would not necessarily improve the system's performance based on the results comparison of authors of Ref.[20] and Ref.[22]. For instance, the difference can be due to the total volume of water heated up and the time taken by the fluid to move from the entrance of the sensor to it exit point.

5. Conclusion

Due to the weather conditions in Nsanke village, we carried out the design and construction of a TSWH according to the need of the population in warm water. The material for the system design were selected with consideration to the design calculations, market availability and

cost of the materials. Using relevant equations, we dimensioned the major components of the system. The system is made up of two flat-plate collectors of 1.68 m^2 each, consisting of absorber plate carrying copper tubes and placed in an insulated casing with a transparent glass cover of 4 mm thickness. The collectors are connected in series and are assumed to operate on the same efficiency. The resultant collector is connected to a storage tank, which is an association of two barrel nested all in all and separated with an insulator. The radiation emitted by the absorber plate cannot escape through the glass, thus increasing its temperature. The system was tested in order to evaluate its performance. From the results obtained, it was clearly shown that the TSWH can heat water from 23°C to at least 51°C during the dry and sunny days when the irradiance levels are higher. This Solar Water Heating system finds useful application and acts as a renewable energy resource in Nsanke village and other localities where there is abundant and consistent sunlight

Conflicts of interest

The authors declare that they do not have any conflict of interest for the present research work.

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