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Heat Absorption and Conversion Thermal Efficiency Analysis on Mass Concrete Embedded Water Pipes as Permanent Roof

Jai Shankar V.P.[1,*], V.K. Jebasingh[2]

Abstract

The solar thermal storage ability of concrete roof structures was analyzed by placing water pipes made of galvanized pipes embedded inside the top plaster. The performance parameters such as the inlet and outlet water temperatures, ambient temperature, and solar radiation were recorded and indicate positively on embedding this system in to real-time roof structures. Studies were carried out at Aluva, south west India (10.1004° N, 76.3570° E). The water flow rate was fixed at 0.004 kg/s and was analyzed with inlet flow temperature set at 22°C and from 6.00 am to 8.00 pm with an interval of 1 hour. The study shows that the solar thermal mass could effectively provide hot water even after sunset, thus effectively reducing the external energy demand for the building. The maximum and minimum water outlet temperatures were 66°C and 53.1°C in the month of May and November, respectively, during the peak hour and that during the off-peak extremity at 8.00 pm was 33.1°C and 29.4°C during the month of May and June, respectively. The analysis on the heater efficiencies is discussed and the explanation for the same is clearly indicated.

Keywords: Solar thermal storage, galvanized pipes, water temperature, top plaster, solar radiation, roof structure

INTRODUCTION

Ever since humans have ventured into the age of development to establish themselves as the dominant species, the demand for energy has grown exponentially. Many methods have been implemented since the ages known, to extract energy from various naturally available forms. The use of solar energy in various forms has been in use from a very early age itself. The conversion of solar energy in economic and efficient way has always been a challenging thing that acquired momentum only in the recent past.

*Author for Correspondence
Jai Shankar V.P.
E-mail: jvpmescet@gmail.com

[1]Research Scholar, Department of Mechanical Engineering, Noorul Islam Centre of Higher Education (NICHE), Kanyakumari, Tamilnadu, India
[2]Assistant Professor, Department of Marine Engineering, Noorul Islam Centre of Higher Education (NICHE), Kanyakumari, Tamilnadu, India

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Mass concrete embedded water pipes is a very much less explored field that has gained momentum is recent past and has stopped after the studies had shifted to the use of phase change materials [1].

The main advantage of using mass concrete embedded water pipes is that the same in temperate climate can reduce the overall temperature inside the building/reduce the cooling load of the air-conditioning unit. The use of galvanized iron (GI) pipes as the water carrier and embedding it just below the main concreate has never been done before. This can be done on existing building, low cost, standalone unit, same area can tube used unlike the conventional solar water heaters that makes the space it is kept obsolete. The excellent thermal mass of concrete and its use as a base construction material in many countries serves as a main option for the use of mass concrete embedded water pipes (MCEWP) to be used as a source of harnessing solar energy.

Many researchers have used polymers as pipe material. But cyclic thermal loading has led this to failure after a certain time. Barbosa et al. [2] investigated the low-cost solar heaters using a parallel and series combination of polyvinyl chloride tube and polyethylene terephthalate. It is reported that an output of 40.9% at a temperature of 49.7°C. Filipovic et al. [3] conducted the experimentation for flat-plate solar collector (FPC) used the polymer material for construction to reduce the cost of the FPC. Sun et al. [4] conducted an experiment on a ceramic solar water heater being installed on the roof of a residential building. It is concluded that the solar collector with a ceramic style has attained maximum temperature and energy conversion efficiency of 56°C and 50%, respectively.

Some others have used phase change materials or nano materials as transportation and storage material. The cost-wise study and the maintenance for the same itself was so high that the same could not be applied in a real-life situation. Manoj Kumar et al. [5] conducted experiments to enhance the performance of the evacuated tube solar water heater with the hybrid nano phase change materials. It was concluded that the thermal energy conversion efficiency and exergy efficiency are improved by 19.4% and 1.28%, respectively, compared to the conventional collector. Manoj Kumar et al. [6] reported a 33.34% improvement in thermal conductivity due to the incorporation of phase change material by dispersing 2.0 mass fraction of silica nanoparticles in the water storage tank.

Some articles have come up with the shape of the collector for the effectively harnessing of the energy. Harmim et al. [7] conducted the experiments with the parabolic reflector in an integrated collector storage solar water heater (ICSSWH) for Algerian climatic conditions. It was reported that the average hot water temperature of 47.3°C for outlet water. Pathak et al. [8] fabricated the two solar FPC absorbers, one with the corrugated absorber and another one with a rectangular absorber. It is reported that the rectangular absorber has shown an improved energy efficiency of 18.4% compared to the single-corrugated absorber collector. Armenta-Deu [9] analyzed the performance of the solar water heater with a semi-sphere solar absorber area. It was reported that the incident solar radiation and the absorber area plays a vital role in the performance of the collector.

Copper pipes were used in some studies as piping material. Hazami et al. [10] investigated the solar concrete wall collector (SCWC) with the integrated solar storage collector (ISSC) for thermal energy storage application. The SCWC system tubes are designed with the serpentine shape and made of copper. The obtained maximum hot water temperature for the energy consumption of 50°C has been recorded for SCWC. Sable [11] constructed the concrete solar water collector comprising copper serpentine tube and metal fibers to enhance the performance of the collector. The simple configuration is made in the serpentine flow pipes to improve the heat-transfer rate. It was concluded that the concrete collector obtained the temperature in the range of 59°C to 69°C.

Patil et al. [12] investigated the SCWC system which produced the average outlet temperature of 58°C, with an output of 38% of the energy conversion efficiency. Some studies have identified the use of concrete embedded water pipes. Ji et al. [13] investigated the roof-integrated cement concrete solar collector (RCCSC) for cooling and hot water production for residential building during the summer climatic condition. It has been reported that the system maximum water outlet temperature of 42.5°C. Sarachitti et al. [14] analyzed the energy and economics of the RCCSC system for cooling and hot water production of the building. It was reported the integration of the RCCSC system reduces the cooling load of the building by about 2.05% compared to the conventional building. The building-integraged solar water collector (BISWC) can be used as the envelope and façade of the building application in addition to the hot water production. O'Hegarty et al. [15] fabricated a concrete collector and integrated it into a Dublin apartment building for hot water production.

As discussed above, researches have investigated different shapes, materials for pipe and fluid for increasing the efficiency of the system. The general purpose of these were to harness the solar energy/increase the effectiveness but none has done any works regarding the reduction of the cooling load.

A series of clear-cut work on embedding the water pipes for harnessing solar energy was done by Chaurasia [16]. Chaurasia's work was regarding the construction of a solar concrete collector and checking its effectiveness as a water heater. The work was a success and suggested that concrete roof structures with water jackets may be used to provide the hot water needs of the inmates. The work is a follow-up of his work in the years 1990 and 1995 but no valid reference is available regarding this.

In the year 2000, Chaurasia [17] came with a most apprised work. He used thin unglazed cement concrete slabs with network of aluminum pipes embedded over its surface. The work was a huge success and concludes with an appeal on designers and architects on using the same for roof construction.

The possibility of embedding the same in to the roof structure proves to be a much complex effort and the pipe can be put in the plaster above the concrete, embedding the pipe completely.

METHODOLOGY AND PARAMETERS

The experimental set up was done at Aluva, southwest India (10.1004° N, 76.3570° E). The dimensions of the setup were 100 cm length, 100 cm width 10 cm height of concrete thickness. The setup is made by plastering the top layer of the concrete slab with water pipe embedded at a specified pitch of 15 cm [18].

Computational analysis showed that the optimum diameter of the copper pipe was 3/8 inch (0.9525 cm). With the 0.9525 cm of pipe embedded, the thickness of the slab plaster (optimum value 10 mm) had to be altered to a minimum of 20 cm and above. At this thickness above 10 cm the plaster is prone to crack owing to larger pipe diameter, which was experimented. Moreover, the value of pipe diameter 0.9525 cm gives only small thickness for fully embedding and the pipe dimension 3/8 inch (0.9525 cm) was not a standard one. Above all the material had a problem – copper is costly and cannot withstand high loads that it has to experience.

Thus, the material and its dimension were altered to GI pipe with ¼ inch diameter to accommodate for the above said problems. Initially, the slab was cast and the plaster of 20 mm with ¼ inch GI pipe at 15 cm pitch was laid (Figure 1). This led to the cracking of the plaster. Then it was understood that the plaster thickness cannot be higher than 10 mm (standard value 9 mm). A new solution was derived where first a 10 mm plaster was laid in which the pipes will be laid in 50% exposed condition and then the remaining will be laid once it is strong enough, before fully getting cured.

The values of the solar radiation, inlet temperature of water, outlet temperature of water, and ambient temperature were measured for a period of one year, with three sets of readings taken each month. Water was circulated continuously at 0.004 kg/s with inlet temperature of water stabilized at 22°C. The outlet temperature of water was measured, and solar radiation was measures simultaneously.

Table 1 shows the specification of the components used in the proposed system.

The thermal energy conversion efficiency was calculated by equation taken by Karthick et al. [19].

$$\eta_c = \frac{Q_w}{Q_{in}} 100$$

The heat absorbed is given by

$$Q_w = mC_p \Delta T$$

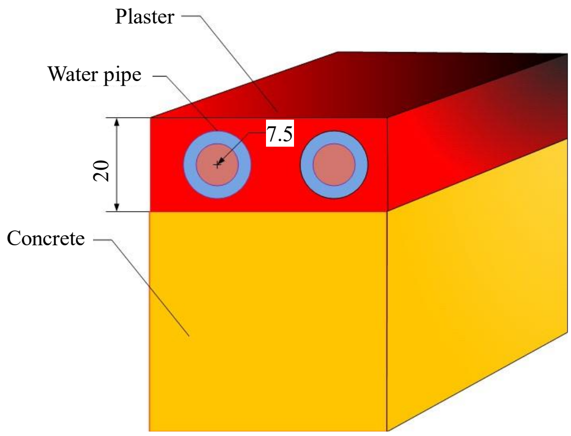

Figure 1. Pipe being embedded in the setup.

Table 1. Components used.

Component	Specification
Pipe	Galvanized iron pipe, ¼ inch diameter
Slab thickness	10 cm + 20 mm plaster = 12 cm
Collector area	1 m × 1 m= 1 m2
Thermometer	0–100°C
Thermocouple	0–100°C
Solar radiation meter	0–2500 W/m2

RESULTS AND DISCUSSION

The values of conversion thermal efficiency were taken for study. Figure 2 shows the conversion thermal efficiency for January, April, July, and October for the year 2022. The efficiency increases to a very high value in the morning and in the afternoon and to infinity suggesting that the effective computation of the conversion thermal efficiency should be only done on a macro scale. Also, it may be accounted that the availability of heat will be higher even after the highest solar output point has passed suggesting that the thermal mass storage of concrete is excellent.

Figure 3 shows the heat absorbed by running water on an hourly basis. From this it is evident that the heat extraction continuous even after the sun set. This means that the comfort condition can be enhanced even after the sun has set. Also, the hot water storage will provide water for washing and bathing.

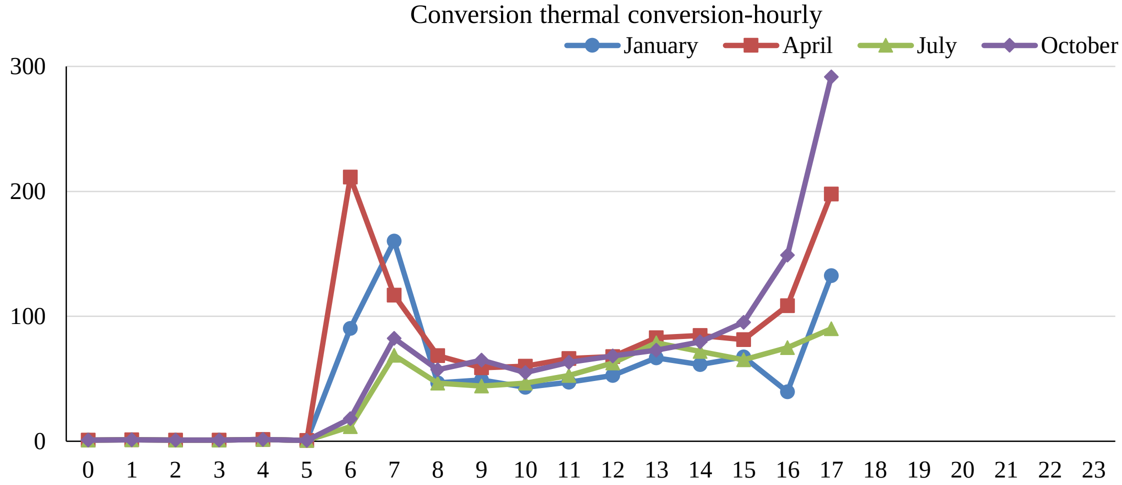

Figure 2. Conversion thermal efficiency versus time for January, April, July, and October 2022.

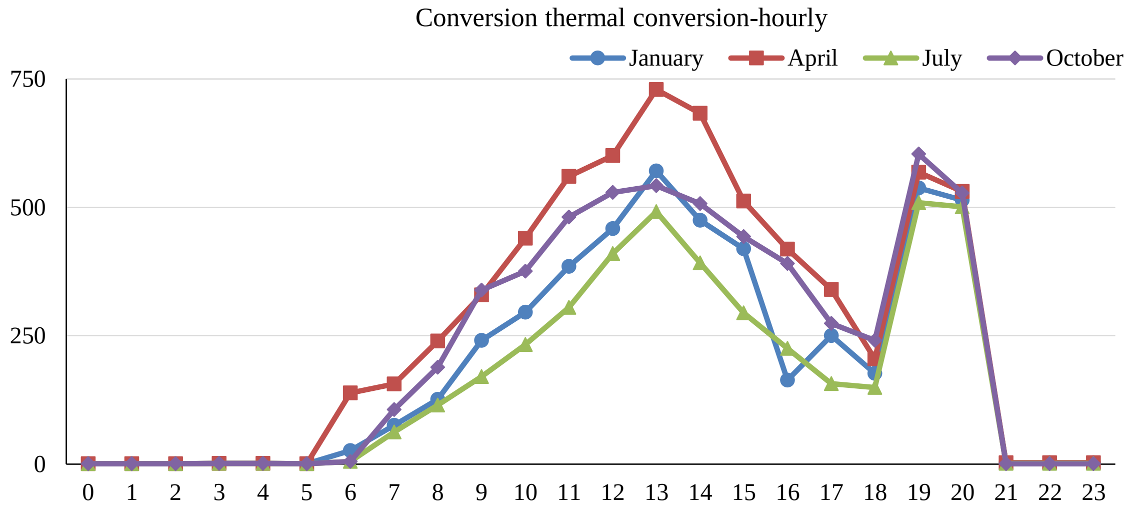

Figure 3. Heat absorbed versus time for January, April, July, and October 2022.

CONCLUSION

The experiments were conducted from December 2021 to November 2022. Results show that heat extraction will take place even after 6:00 in the evening, hence comfort conditions will continue to be improved even after the sun has set. The analysis on efficiency show that the efficiency analysis cannot be directly used for hourly computation purpose by only for daily cases.

The results show that the inside comfort conditions of a house will be improved by using the water embedded pipes in concrete roof structures. The study shows there is a need to find the decrease in the energy demand of the air-conditioning unit when this system is used.

NOMENCLATURE

MCEWP	Mass concrete embedded water pipes
PCM	Phase change material
ICSSWH	Integrated collector storage solar water heater
SCWC	Solar concrete wall collector
RCCSC	Roof-integrated cement concrete solar collector
BISWC	Building-integrated solar water collector

LIST OF SYMBOLS

η_c = Conversion thermal efficiency
Q_w = Heat taken by water
Q_{in} = Heat input in terms of solar radiation
$m = 0.004$ kg/s = Mass flow rate of water
$C_p = 4200$ kJ/kg = heat capacity of water
ΔT = Temperature gradient

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