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THERMAL PERFORMANCE OF CURTAIN WALL INTEGRATED SOLAR WATER HEATER WITH NANOFLUID

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***Abstract:** In this study efforts have been made to develop and test wall-integrated solar water heating system which uses the CuO + Graphene (5ml) /H2O nanofluid. The thermal performance of an innovative curtain wall-integrated solar water heater with CuO + Graphene (5ml) /H2O nanofluid investigated experimentally. The effect of variation in mass flow rate of cooling water [5, 10, 15 and 20 LPH] on instantaneous collector efficiency is evaluated. Graphene is used as surfactant and added in the nanofluid as to increase the settling time of the nanoparticle in nanofluid. Thermal performance of innovative curtain wall integrated solar water heater can be improved by using CuO + Graphene (5ml) /H2O nanofluid The instantaneous collector efficiency of the developed model increases with an increase in the mass flow rate of the water. The instantaneous efficiency of the developed model increases with an increase in the volume concentration of nanofluid. Outlet temperature of hot water increases with increase in intensity of solar radiation and volume concentration of nanofluid. Within the exterior wall of light steel houses, developed model can be used as an environmental control device that can "harvest" solar thermal energy. This device should effectively buffer the solar heat gain and even capture this heat energy and transfer it in such a way that it can be used*

***Keywords:** Solar energy, solar water heater system,CuO + Graphene (5ml) /H2O nanofluid, curtain wall, etc.*

I. INTRODUCTION

Energy is the basic need of all human beings because it not only drives the economy of a country but also leads to the technological development. World energy use is increasing day by day particularly from the fossil fuels due to the industrialization, increasing world population and living standard of people in the developing countries. Fossil fuels cannot be newly formed at any significant rate therefore, the present stocks are finite. The dominant fossil fuel type by mass is coal, with oil and gas much lesser. The reserve lifetime of any resource may be defined as the ratio of accessible amount and the rate of its present use. By the above definition, it can be predicted that the lifetime of oil and gas resources is only for a few decades however, the lifetime of coal is for few centuries. As the lifetime of a fuel reserve decreases, the fuel price increases therefore, demand for that fuel reduces and less expensive and alternatives sources enter the market. As of now, the total power generation capacity of India is approximately 201637.03 MW, in which the share of thermal power is 133363.18 MW (66.14%) which is the major contributor in the total power generation of the country followed by hydro power 38990.40 MW (19.33%), nuclear power 4780 MW (2.37%) and renewable energy sources 24503.45 MW (12.15%) [1]. India being a tropical country, having long sunshine hours per day with a much better average solar intensity of 500 W/m2, therefore has a great potential as future energy resource. It also has the advantage of permitting the decentralized distribution of energy, thereby, empowering the people at the grassroots level. Keeping the above aspect in mind, the Govt. of India has launched the Jawaharlal Nehru Solar Mission to promote ecologically sustainable growth while addressing the energy security challenge of the country. The National Action Plan on Climate Change has been launched on June 30, 2008 and the target of solar mission was to produce 20,000 MW of power by 2022 using solar energy [2].

1.1 Solar Power in India

Energy resources are getting depleted day by day at a very alarming rate. Continuous research is going on around the world to harness energy from other renewable sources. While we think of the word "Renewable" the very first thing that comes to our mind is "Solar". With about 300 clear, sunny days in a year, India receives about 5 Petawatt-hours per year (PWh/year) (i.e; 5 trillion Kwhr/day). The daily average solar energy incident over India varies from 4 to 7 kWh/m2 with about 1500–2000 sunshine hours per year), which is far more than current total energy consumption.

Solar heater is a device which is used for heating the water, for producing the steam for domestic and industrial purposes by utilizing the solar energy. Solar energy is the energy which is coming from sun in the form of solar radiations in infinite amount, when these solar radiations falls on absorbing surface, then they gets converted into the heat, this heat is used for heating the water. This type of thermal collector suffers from heat losses due to radiation and convection. Such losses increase rapidly as the temperature of the working fluid increases [4].

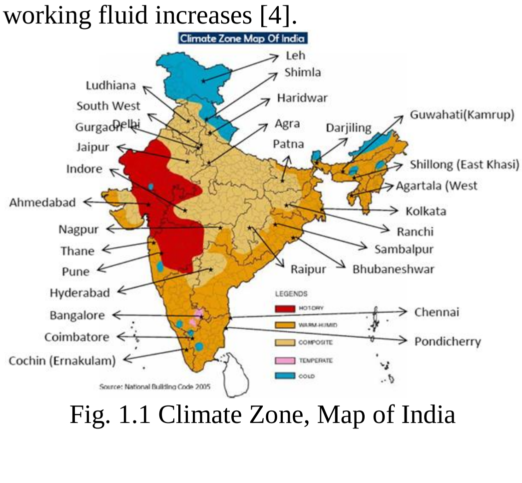

Fig. 1.1 Climate Zone, Map of India

1.2 The Concept of Nanofluid

The concept of Nano-fluids is developed at Argonne National laboratory (Choi, 1995) is directly related to trends in miniaturization and nanotechnology. Recent reviews of research programs on nanotechnology in the U. S., China, Europe, and Japan show that nanotechnology will be an emerging and exciting technology of the 21st century and that universities, national laboratories, small businesses, and large multinational companies have already established nanotechnology research groups or interdisciplinary centers that focus on nanotechnology. It is estimated that nanotechnology is at a similar level of development as computer/information technology was in the 1950s [5]. Solids have orders-of-magnitude higher thermal conductivities than those of conventional heat transfer fluids. For example, the thermal conductivity of copper at room temperature is about 3000 times greater than that of engine oil. Therefore, solid particles in fluids are expected to enhance the thermal conductivities of fluids. In fact, numerous theoretical and experimental studies of the effective thermal conductivity of dispersions that contain solid particles have been conducted since Maxwell's theoretical work was published more than 100 years ago.

Figure 1.2 shows the thermal conductivity of typical materials. Solids have thermal conductivities that are orders of magnitude greater than those of traditional heat transfer fluids.

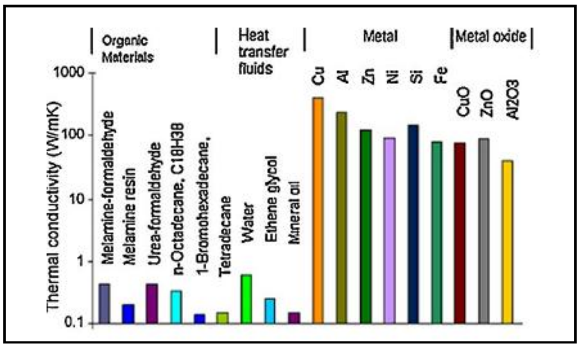

Fig 1.2 Thermal Conductivity of Typical Materials

However, all of the studies on thermal conductivity of suspensions have been confined to millimeter- or micro meter-sized particles. The major problem with these particles is their rapid settling in fluids. In recent years, nanotechnology has enabled the production of Nanoparticles with average sizes below 50 nm. Nanoparticles at this scale have unique properties. Applying this emerging nanotechnology to established thermal energy engineering, Argonne developed the concept of nanofluids (Choi, 1995), a new and innovative class of heat transfer fluids that are engineered by suspending Nanoparticles in conventional heat transfer fluids [6]. Maxwell's concept of enhancing the thermal conductivity of fluids by dispersing solid particles is old, but what is new and innovative with the concept of nanofluids is the idea of using the nanometer-sized particles that have become available only recently. These very small particles remain in suspension almost indefinitely and also provide high surface area densities. Because of the "square/cube law," the surface-area-to-volume ratio of nanoparticles is three orders of magnitude greater than that of micro particles. They show that "size does matter" in the concept of nanofluids. For this reason, nanofluids are a rapidly emerging field in which nanoscience and thermal engineering meet.

1.2.1 Hybrid Nanofluid

Nano composites, i.e., composites containing dispersed particles in the nanometer range, are significant part of nanotechnology and one of the fastest growing areas in material science and engineering. Alumina (Al_2O_3) is a ceramic material that exhibit several excellent properties such as very good stability and chemical inertness. But Al_2O_3 has lower conductivity compared to metallic nanoparticles. Metallic nanoparticles such as copper (Cu), aluminum (Al) possess very high thermal conductivities. But stability and reactivity are two important factors that always impede the use of metallic nanoparticles in the nanofluid applications. The incorporation of small amount of metal particles into an ammonia matrix can significantly improve the thermal properties [7].

1.2.2 Particle Material and Base Fluid

Many different particle materials are used for nanofluid preparation. Al_2O_3, CuO, TiO_2, SiC, TiC, Ag, Au, Cu, and Fe nanoparticles are frequently used in nanofluid research. Carbon nanotubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction. Base fluids mostly used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene, glycol and engine oil. In order to improve the stability of nanoparticles inside the base fluid, some additives are added to the mixture in small amounts.

1.2.3 Particle Size

Nanoparticles used in nanofluid preparation usually have diameters below 100nm. The small particle up to 10 nm has been used in nanofluid research. When particles are not spherical but rod or tube-shaped, the diameter is still below 100nm, but the length of the particles may be on the order of micrometers. It should also be noted that due to the clustering phenomenon, particles may form clusters with sizes on the order of micrometers.

1.3.4 Particle Shape

Spherical particles are mostly used in nanofluids. However, rod-shaped, tube-shaped and disk-shaped nanoparticles are also used. On the other hand, the clusters formed by nanoparticles may have fractal-like shapes [8].

II. EXPERIMENTAL SETUP

The experimental test cell can be consist of an exterior wall copper plate (1), a vertical flow duct with a square cross section (2), a circulation loop (3), and a cooling sleeve (4). The exterior wall (1) width can be 40 cm and the height could be 80 cm, which is a commonly used curtain wall height.

On one side of the wall, solar radiation are used to heat the

wall surface, simulating the solar radiation received by the exterior wall plate on the other side (inside the curtain wall), the vertical flow duct measured 30 mm wide by 20 mm high and can be welded specifically to form a heat exchanger. The circulation tube (3) uses as structural support for the curtain wall; therefore, the tube material used in this study can be copper. The joint between the circulation tube and square duct is constructed with filet material, and the tubes are shaped to maintain a constant cross-sectional area throughout the circulation loop. The outer radius of the tube is 12.7 mm, the inner radius is 11 mm, and the wall thickness is 1.7 mm.
To align the loop with the exterior wall, we have fixed the horizontal distance S to be approximately 200 mm to match the typical wall thickness. Therefore, the overall exterior size of the test cell was 60 cm wide, 20 cm deep, and 80 cm high, which matches the dimensions of typical metal curtain walls. In addition, valves were installed at the top and bottom of the loop to allow for the removal and addition of fluid. The cooling section (4) is installed at opposite the heated section. This section includes a cylindrical cooling sleeve made of aluminum. In addition, the cooled section uses water from a thermally regulated bath to extract heat from the loop. The cooling sleeve measured 50 mm × 215 mm and had internal dimensions of 48 mm × 210 mm. Cotton is be wrapped around the cooled section and the exterior of the circulation tube as insulation to reduce heat losses from the system. Desired radiation intensity measurements are taken using a pyranometer. We installed resistance temperature detector (RTD) at various points around the loop to measure the water inlet and outlet temperature In addition, we have installed the resistance temperature detectors (RTDs) at the cooling water entrance and exit in the cooling sleeve.

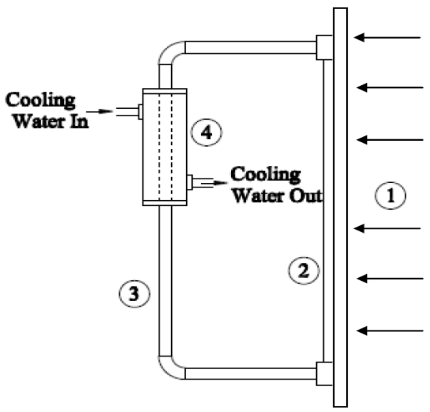

Fig.2.1 Schematic Diagram

2.1 Specifications of Experimental set up
2.1.1 Exterior wall plate specifications
Thickness of plate -2mm
Length – 60 cm
Height – 80 cm
Material - copper

2.1.2Vertical flow duct
Vertical flow duct having square cross section is used for natural circulation of nano fluid.
Dimensions – 2×2 cm
Length – 60 cm
Cross section – square
Material – copper

2.1.3 Cooling Sleeve
The Cooling sleeve which acts as a heat exchanger. It has cylindrical cross section, the copper pipe which contains nano fluid passes through it and base fluid (water) is flowing through it.
Height - 21.5 cm
Diameter - 5 cm
Material- aluminium
Cross section- cylindrical

2.2 Development of Mathematical Model
Mathematical Modelingis framing questions in/about the real world in mathematical terms. It includes
- Building a mathematical model (representation) of the real world.
- Studying the mathematical model using known mathematical tools and techniques.
- Interpreting the results of the mathematical investigations in terms of the original real-world problem.

The mathematical model of solar collector consists of external energy balance of absorber and internal energy balance of absorber. Model solves the energy balance of solar collector under steady-state condition were taken into considerations.

2.2.1 Assumptions Made in Developing Mathematical Model
Assumptions made before developing mathematical model:
- Temperature stratification of the water within the tank is neglected as a first approximation.
- Diffuse radiation is neglected.
- Adiabatic side and bottom surfaces of the SWH.
- Constant ambient temperature.
- The regular flow and in case stability in the pipeline.
- There is no energy stored in the glass cover and absorber plate.
- The neglect of the temperature difference through the glass cover.
- The properties of the fluid constant.

The useful energy can also be expressed in terms of the energy absorbed by the absorber and the energy lost from the absorber.

$$Q_u = m\, Cp\, (To - Ti) \quad (2.1)$$

$$Qu = Ac\, F_{R\,[}(G_T\,(\zeta\alpha) - U_L(Ti - Ta)] \quad (2.2)$$

The instantaneous collector efficiency relates the useful energy to the total radiation incident on the collector surface by Eq. (3.6) or

$$\eta_{i\,=}\, Q_u/\,(A_c\, G_T) = [m\, C_p\, (T_o - T_i)]/[\,A_c\, G_T]$$

$$\eta_{i\,=}\, F_R\,(\zeta\alpha) - F_R U_L[(Ti - Ta)/\,G_T] \quad (2.3)$$

The rate of thermal energy input *(Q_{in})*, the rate of thermal energy gain *(Q_g)* and the instantaneous efficiency *(η)* of each collector were calculated as below:

$Q_{in} = I_t . A_{coll}$(2.4)
Where,
$A_{coll}$is the area of collector

Measuring the collector area on which solar radiations fall we get,

$Q_g = m\, C_w\, (T_o\text{-}T_i)$(2.5)
Where,
m is mass flow rate and *Cp* is specific heat of water

$\eta_{inst}= Q_g / Q_{in}$(2.6)
Where,
η_{inst} is the instantaneous efficiency

Considering the parameter affecting on the collector efficiency i.e. volume fraction of nanofluid, mass flow rate of cooling water mathematical model can be developed. The developed model can help to analyze the effect of said parameters on the efficiency of flat plate solar collector. In addition to this, correlations available in literVolume of nanofluid. Thus for given volume fraction of nanofluid and decided amount of nanofluid to be prepared the mass of nanoparticle to be added in the base fluid can be calculated. As the quantity of nanopowder required for the same for volume fraction basis is large and considering the cost of same it will be later decided the weathered to conduct the experiment with preparation of nanofluid on volume basis or weight basis. Nature to find the properties of nanofluid can be utilized. The correlations are as follows,

2.3 Nanofluids Thermal and Flow Properties
The thermal and flow properties of nanofluid are calculated using different available correlations as below:
Thermal conductivity using Timofeeva correlations as below:

$$K_{nf} = [1+3\phi]K_w \quad (2.7)$$

Viscosity of nanofluid using Drew and Pass man correlations as below:

$$\mu_{nf} = [1+2.5\phi]\mu_w \quad \mathbf{(2.8)}$$

The density and specific heat using **Pak and Cho** correlations as below

$$\rho_{nf} = \phi\rho_{np} + (1-\phi)\rho_w \quad \mathbf{(2.9)}$$

$$Cp_{nf} = \phi Cp_{np} + (1-\phi)Cp_w \quad \mathbf{(2.10)}$$

2.4 Preparation of Nanofluid
The selected nanopowder for the proposed study is Copper oxide (CuO)-40 nm size and Graphene as surfactant with water as base fluid. The nanopowder is purchased from the Sisco Laboratories Mumbai. The amount of nanopowder required for the same can be calculated as below.

The total volume of nanofluid to be prepared =
Volume of collector pipes + Volume of heade pipe + Volume of footer pipe + Volume of nanofluid filled by the connecting pipes of the set up + Volume of nanofluid occupied by the pipes in the heat exchanger
The amount of nanopowder required is calculated by,
Vol. fraction of nanofluid (%) = Vol. of Nanoparticle/Vol. of Nanofluid
But,
Vol. of nanoparticle = Mass of nanoparticle / Density of nanoparticle
Hence Volume fraction of nanofluid is,
= (Mass of nanoparticle/Density of nanoparticle)

III. TESTING METHODOLOGY

This chapter depicts test methodology that has been implemented for testing developed curtain wall integrated solar water heater with different volume concentration of nanofluid. Sample observation tables are also given for testing of developed model for different flow rates and different volume concentration of nano fluid. In addition this chapter gives the data reduction and sample calculations for test methodology.

3.1 Experimental Testing Methodology and Data Reduction
In order to Thermal performance of curtain wall-integrated solar water heater with CuO + Graphene (5ml) /H_2O nanofluid it has been decided to vary the mass flow rate from 5 LPH to 20 LPH in the step of 5 LPH. Heat exchanger is placed at backside of collector. Cold water is get supplied to heat exchanger, it absorb heat from hot fluid. Whole test set up is mounted vertically. Firstly the duct is filled with water manually and is used as an exchange of heat in the cooling sleeve. Then the water is circulated through the flexible pipe which fills through the cooling sleeve using a motor/pump. The inlet temperature of the water is measured as "Ti' whereas the outlet temperature is 'To'. The solar radiations are incident on the collector plate which absorbs the radiations and gets heated. This heat is transferred to the fluid in the duct and heat is eventually convicted to the water. This transferred heat heats the water and its temperature increases. The various readings for 'Ti' and 'To' are taken throughout the day. The readings are taken between 11:00 AM – 04:00 PM. The above procedure is repeated by changing the fluid in the duct. Nano-particles are added by volume percentage to water to form the nanofluid. Various concentrations are taken for the experiment. The flow rates are varied simultaneously for the various concentrations of the nanofluids. The flow rates are 5 LPH, 10 LPH, 15 LPH and 20 LPH. The rate of thermal energy input *(Q_{in})*, the rate of thermal energy gain *(Q_g)* and the instantaneous efficiency *(η)* of each collector were calculated as below:
$Q_{in} = I_t. A_{coll}$ (3.1)
Where,
$A_{coll}$is the area of collector.
Measuring the collector area on which solar radiations fall we get,
$Q_g = m\, C_w\, (T_o\text{-}T_i)$ (3.2)
Where,
m is mass flow rate and Cp is specific heat of water
$\eta_{inst}= Q_g / Q_{in}$ (3.3)
Where,

η_{inst} is the instantaneous efficiency

3.2 Observation Tables for Testing of Curtain Wall Integrated Solar Water Heater with Water for Different Flow Rates

Table 3.1 Water as Working Fluid with Flow Rate 5 LPH

Sr.No.	Time	Intensity of Solar Radiation	Flow rate (Q)	T_{in}	T_{out}	ΔT
	am/pm	W/m^2	LPH	^oC	^oC	^oC
1	11:00	588.546	5	28.1	34.1	6
2	11:30	602	5	28.1	35.6	7.5
3	12:00	644.266	5	28.2	36.4	8.2
4	12:30	654.605	5	28	37.2	9.2
5	1:00	655.669	5	27.9	38	10.1
6	1:30	658.273	5	27.8	37.9	10.1
7	2:00	656.075	5	27.8	36.8	9
8	2:30	641.424	5	27.9	36.3	8.4
9	3:00	588.42	5	27.8	35.9	8.1
10	3:30	577.71	5	27.7	34.7	7
11	4:00	567.42	5	27.6	34.3	6.7

Table 3.2Water as Working Fluid with Flow Rate 10 LPH

Sr.No.	Time	Intensity of Solar Radiation	Flow rate (Q)	T_{in}	T_{out}	ΔT
	am/pm	W/m^2	LPH	^oC	^oC	^oC
1	11:00	583.65	10	27.9	31.5	3.6
2	11:30	603.24	10	27.9	32.2	4.3
3	12:00	641.23	10	28.1	32.4	4.3
4	12:30	653.24	10	28.2	33.2	5
5	1:00	652.36	10	28.3	33.4	5.1
6	1:30	655.36	10	28.1	33.9	5.8
7	2:00	657.68	10	27.8	33	5.2
8	2:30	642.36	10	27.6	32.3	4.7
9	3:00	592.36	10	27.6	31.9	4.3
10	3:30	570.23	10	27.5	31.7	4.2
11	4:00	565.38	10	27.5	31.3	3.8

Table 3.3Water as Working Fluid with Flow Rate 15 LPH

Sr.No.	Time	Intensity of Solar Radiation	Flow rate (Q)	T_{in}	T_{out}	ΔT
	am/pm	W/m^2	LPH	^oC	^oC	^oC
1	11:00	586.35	15	28.1	30.6	2.5
2	11:30	602.42	15	28.1	31	2.9
3	12:00	643.58	15	28.2	31.5	3.3
4	12:30	653.24	15	28	31.5	3.5
5	1:00	654.25	15	28.9	31.7	3.8
6	1:30	655.26	15	27.8	31.4	3.6
7	2:00	655.38	15	27.8	31.3	3.5
8	2:30	640.24	15	27.9	31.2	3.3
9	3:00	587.014	15	27.8	30.8	3
10	3:30	575.14	15	27.7	30.4	2.7
11	4:00	566.45	15	27.6	30.1	2.5

Table 3.4Water as Working Fluid with Flow Rate 20 LPH

Sr.No.	Time	Intensity of Solar Radiation	Flow rate (Q)	T_{in}	T_{out}	ΔT
	am/pm	W/m^2	LPH	^oC	^oC	^oC
1	11:00	587.35	20	27.9	29.9	2
2	11:30	604.25	20	27.9	30.2	2.3
3	12:00	641.25	20	28.1	30.6	2.5
4	12:30	655.014	20	28.2	30.9	2.7
5	1:00	654.28	20	28.3	31.2	2.9
6	1:30	658.36	20	28.1	31	2.9
7	2:00	657.36	20	27.8	30.6	2.8
8	2:30	640.125	20	27.6	30.2	2.6
9	3:00	587.36	20	27.6	29.9	2.3
10	3:30	576.39	20	27.5	29.7	2.2
11	4:00	566.258	20	27.5	29.5	2

The rate of thermal energy input(Q_{in}), the rate of thermal energy gain(Q_g) and the instantaneous efficiency (η) of wall were calculated as below

$Q_{in} = I_t . A_{wall}$ (3.4)

Where,

$A_{wall}$is the area of collector wall

Measuring the collector area on which solar radiations fall we get,

$A_{coll} = 0.21\ m^2$

$Q_{in} = I_t . A_{coll}$

$= 584.23 \times 0.21$

$= 122.68W$

$Q_g = m_w C_p (T_o - T_i)$ (3.5)

Where,

m is mass flow rate and Cp is specific heat of water

$= 0.005555 \times 4183 \times (30.8-28.1)$

$= 62.75W$

Instantaneous efficiency we can find out,

$\eta_{inst} = Q_g / Q_{in}$ (3.6)

$=62.75/122.68$

$= 51.14\ \%$

Where,

η_{inst} is the instantaneous efficiency

IV. CONCLUSION

The thermal performance of an innovative curtain wall-integrated solar water heater with CuO + Graphene (5ml) /H2O nanofluid investigated experimentally. The effect of variation in mass flow rate of cooling water [5, 10, 15 and 20 LPH] on instantaneous collector efficiency is evaluated. Graphene is used as surfactant and added in the nanofluid as to increase the settling time of the nanoparticle in nanofluid.

Following conclusions are made from the above mentioned experimental study and is detailed below:

- Thermal performance of innovative curtain wall integrated solar water heater can be improved by using CuO + Graphene (5ml) /H_2O nanofluid
- The instantaneous collector efficiency of the developed model increases with an increase in the mass flow rate of the water.

- Within the exterior wall of light steel houses, developed model can be used as an environmental control device that can "harvest" solar thermal energy.
- This device should effectively buffer the solar heat gain and even capture this heat energy and transfer it in such a way that it can be used

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