Knowledge Gaps and Experimental Methodology for Sustainable Concrete Roof Cooling Using Pulsating Heat Pipes

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Abstract: Nowadays, most of the houses and buildings are made with concrete roof. One of the major problem with concrete roof is it gets heated in hot summer. This causes thermal discomfort to occupants as the concrete roof radiates heat into the rooms. Literature survey shows that researchers have attempted various methods to keep the concrete roof temperature low. These methods include green roof, cool roof, roof pond, cooling with phase change material, etc. However these methods have disadvantages like performance degradation, high maintenance cost, and extra weight on roof, water leakage issues, etc. even though all these provide a decrease in roof temperature. Hence, a new method incorporating double layer pulsating heat pipes in concrete roof is attempted in this study. The research methodology includes fabrication of pulsating heat pipes (PHP), preparation of concrete slabs and heat transfer study by integrating PHPs into concrete slabs. An experimental setup to perform the relevant experiments is proposed in this paper. The expected outcomes include estimate of roof temperature reduction, influence of single layer and double layers on roof temperature, influence of working fluid on roof temperature and influence of tilt angle on roof temperature.

Keywords: concrete roof cooling, cool roof, green roof, roof pond, phase change material, pulsating heat pipe.

Introduction

The consumption of energy for providing thermal comfort in houses and various buildings is increasing every year. Nowadays, people build houses and buildings having concrete roof. One of the major disadvantages of concrete roof is that it can act like a thermal storage material. Hence, the concrete roof gets heated during summer and that heat is stored in the concrete roof. At the same time, the roof radiates heat into the rooms causing discomfort to the inhabitants. People use various devices such as air conditioners, coolers, fans etc to overcome this discomfort. This gives extra burden to our power plants as they have to work continuously to meet the extra demand. As the contribution of fossil fuels in electricity generation is still significant this extra power generation leads to environmental impact. In addition, the various thermal stresses experienced by the concrete roof results in roof degradation.

Similarly the urban island effect makes this problem worse in cities and metros. Researchers have attempted various methods such as green roof, PCM based cooling, roof pond, cool roof etc to solve this problem. However, these methods are not implemented commercially due to inherent disadvantages of each of these methods. Hence, a new method employing double layer pulsating heat pipe is proposed in this study. This paper outlines the research methodology, experimental set up and experimental design needed to perform the heat transfer study with pulsating heat pipe integrated concrete slabs. [1-2]

Related work

The literature survey shows that researchers have tried various methods to reduce the temperature of the hot concrete roof. These studies include both experimental and simulation studies on various methods. The existing methods include cool roof, green roof, ventilated roof, asphalt shingles, PCM based cooling, evaporative cooling and roof pond. However, literature survey shows that researches have mainly worked with green roof, cool roof, roof pond, evaporative cooling and PCM based cooling. Cool roof is the application of a reflective coating on the roof surface so that the roof will reflect most of the solar radiation thereby reducing the roof temperature. Green roof suggests the use of vegetation on the top of the roof to reduce the impact of sun on the roof. Roof pond is the artificially maintained pond on the top of the roof to absorb the heat from the sun. Evaporative cooling utilizes spraying of water on the top of the roof and subsequent evaporation to reduce the roof temperature. PCM based cooling employs heat absorption by PCM utilizing latent heat. However these methods have disadvantages like performance degradation, high maintenance cost, and extra weight on roof, water leakage issues, etc. even though all these provide a decrease in roof temperature. [3-7]

These disadvantages suggest that a new method is required to overcome the problem of hot concrete roof. This study involves integrating double layer pulsating heat pipes into concrete. PHPs utilizes boiling and condensation to remove heat from the concrete roof. PHP is a copper coil bent into many turns with ends joined together by brazing. It contains a working fluid (generally distilled water) at ultra-high vacuum. This vacuum allows the water to boil at a lower temperature. PHPs can transfer heat to atmosphere from concrete roof to keep the concrete roof at a lower temperature to provide the necessary thermal comfort.

Research Methodology

The research methodology of this study is given in Figure1. It is mainly an experimental study. It involves fabrication of pulsating heat pipes, preparation of concrete slabs, integration of PHPs inside the concrete and heat transfer study at various operating conditions. Heat transfer study is performed for single and double layers of a PHP, different working fluids, and different tilt angles of concrete slab. The working fluids are distilled water and graphene-water nanofluid. The various tilt angles include 0 degree, 25 degree, 50 degree and 75 degree with the horizontal.

PHPs are made from copper coil having 3.3mm outer diameter and 2.3mm inner diameter. The copper coil is bent into many turns as per the specifications of the concrete slab. PHP is cleaned following an appropriate procedure to remove oily impurities. Later, PHP is tested for leaks before filling the working fluid. The working fluid is filled into the heat pipe using a vacuum pumping system which generate the required vacuum inside the heat pipe. After filling the working fluid, heat pipe is sealed by brazing. Concrete slabs having dimensions 30cm x25cm x 10cm are prepared for various tests. The concrete composition is same as roof concrete employed by construction industry. PHPs are incorporated into the concrete slab during the preparation of the slab. Sufficient curing time is provided to concrete slabs.

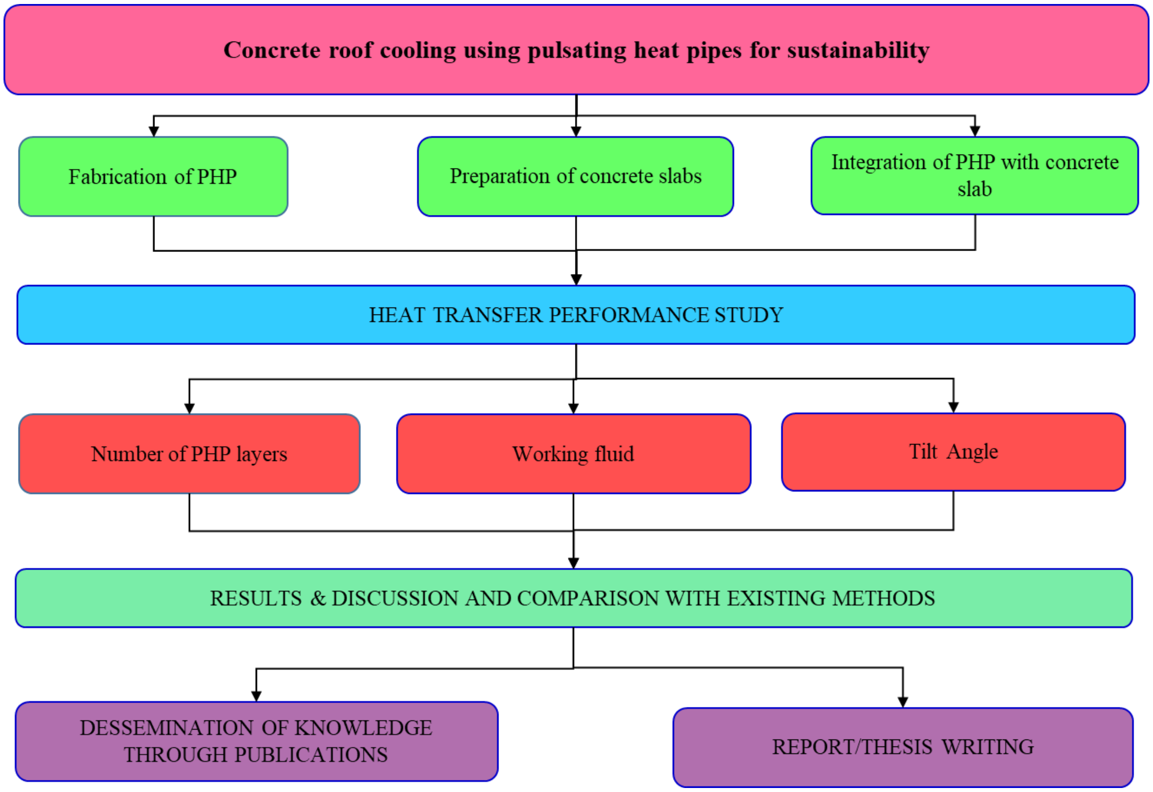

Figure 1 Research Methodology

Experimental setup

Figure 2 shows the proposed experimental set up to analyze the heat transfer performance of concrete-PHP assembly at various operating conditions.

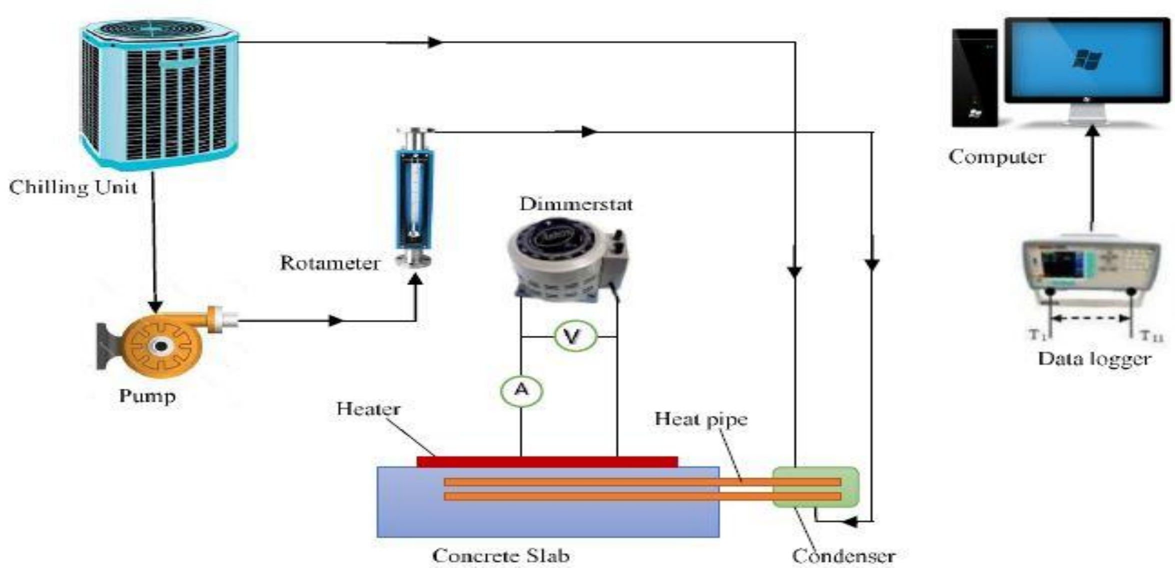

Figure 2 Experimental setup.

It consists of concrete-Pulsating heat pipe assembly, flat plate heater, dimmerstat with voltmeter and ammeter, chilling unit an associated pump and rotameter, thermocouples, data logger and computer. Two flat plate heaters of 1000W capacity is employed in this study to apply heat load. Dimmerstat is used to apply different heat loads to concrete slab. Chilling unit, pump and rotameter are used to supply constant temperature and constant flow rate of water to condenser of PHP. T type thermocouples are used in this study to measure temperature at various state points. All the thermocouples are connected to a data logger and computer is connected to data logger.
Figure 3 is the indication of thermocouple positions on the heater, interface, concrete, heat pipe, cooling water inlet and outlet.

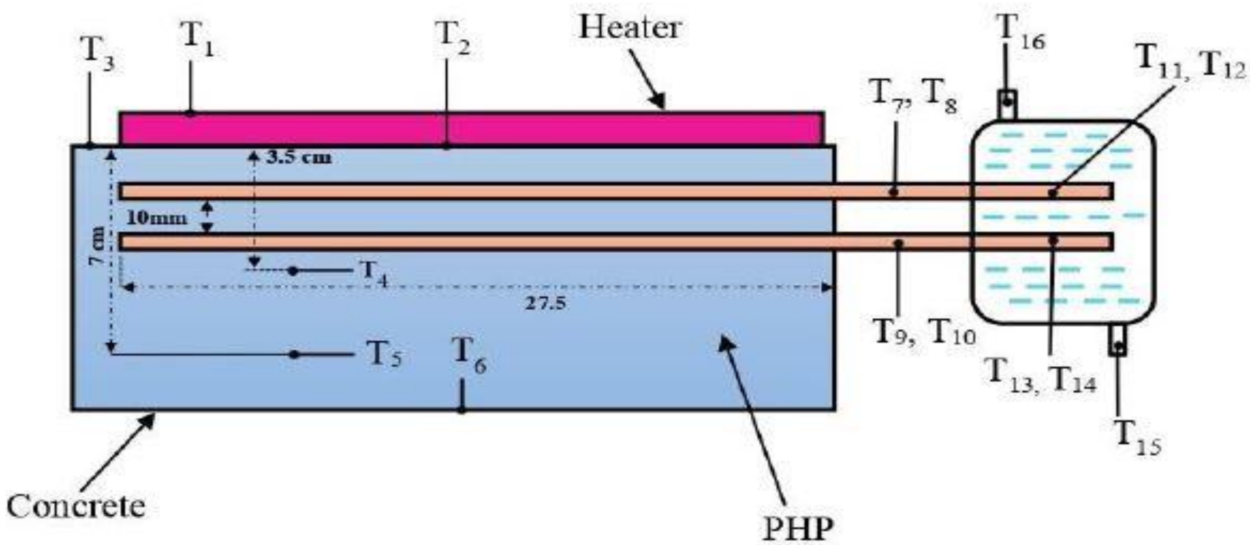

Figure 3 Thermocouple locations at concrete-PHP assembly

Thermocouple 1 gives the temperature at the heater surface. Thermocouple 2 gives the interface temperature between heater and concrete top surface. Thermocouple 3 gives the temperature of the top surface temperature of concrete. Thermocouples 4 and 5 gives the temperatures at the concrete surface at a distance of 3.5cm and 7cm from the top surface. Thermocouple 6 is located at the bottom surface of the concrete. Thermocouple 7 -10 gives the adiabatic temperatures at the PHP. Thermocouple 11-14 gives the temperature at the PHP surface at condenser. Thermocouple 15 and 16 gives the temperature of cooling water at inlet and outlet.

Experimental Procedure

A heat load of 75W is applied on the concrete top surface using flat plate heater. This heat load is equivalent to maximum solar radiation available at the earth's surface. The application of heat load increases the concrete top surface temperature. This heat is gradually transferred to the bottom surface. However, when the heat reaches the PHP layer, PHPs absorb this heat and reject it to atmosphere. If any heat escapes the first layer of PHP, it is captured by the second layer. There is a possibility that a small amount of heat reaches the bottom surface of the concrete. Heat load of 75W is continued for 8 hours to represent day time. All the temperatures are recorded using data logger. Temperatures are also recorded for 6 more hours after heat load is removed to analyze the heat transfer from the concrete.

The same procedure is repeated for single and double layers of PHPs and different working fluids. It is also repeated for different tilt angles of concrete slab. After the experiment, thermocouples are removed and concrete-PHP is separated from experimental set up.

Expected Outcomes

The expected outcomes include estimate of roof temperature reduction, influence of single layer and double layers on roof temperature, influence of working fluid on roof temperature and influence of tilt angle on roof temperature.

Conclusions

Literature survey suggest the need of a new method of concrete roof cooling for the thermal discomfort. In this study, a double layer PHP is suggested for concrete roof cooling. The research methodology clearly indicates the way in which heat transfer study is performed on concrete-PHP assembly at various operating conditions. The experimental setup and procedure are clearly mentioned in this paper. The expected outcomes suggest double layer PHP as a promising solution for concrete roof cooling.

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