

Experimental Investigation and Thermal Analysis of Radiant Floor Cooling System Incorporated with Peltier Effect

Harikrishnan.B¹, Sathil.P.T²

P.G. Student (Thermal Engineering), Department of Mechanical Engineering, Malabar College of Engineering and Technology, Thrissur, Kerala, India¹

Assistant Professor, Department of Mechanical Engineering, Malabar College of Engineering and Technology, Thrissur, Kerala, India²

ABSTRACT: Radiant floor cooling system is an energy efficient method for providing comfort air conditions worked in conjunction with or replacing heating ventilation and air conditioning systems. This system uses water as its working fluid. Other than the chiller systems in commercial buildings, the only working mechanical element for radiant floor cooling system is pump. Thermoelectric generators are the devices which continuously produce electricity if a hot and cold potential is provided on its both faces respectively. These modules work under Seebeck or Peltier effect. This research aims at providing the source of power for running pump and other devices in radiant cooling system utilizing electric current produced from thermoelectric generator. Test setup is generated considering only under-floor cooling technique. This research checks out the variation of amount of electric power generated by TEG for different conditions of radiant floor cooling system.

KEYWORDS: Radiant, floor, cooling, TEG, TEC1-12706, Seebeck, Peltier,module.

I. INTRODUCTION

The importance of the issue “climate and energy” intensely knocked the European countries in 2007. Building sector was responsible for almost 38.5% of energy wastages. This system uses water as its working fluid. A number of advantages set water as the best cooling agent. Mainly, water has higher specific heat capacity than air, and also pumps work more efficiently than fans in heating ventilation and air conditioning systems [1]. The temperature difference made in radiant floor cooling system is low and maintained very close to room temperature. Radiant floor cooling system provides more uniform thermal condition throughout the system compared other to conventional systems [2] and chances of draught are too low [3]. Radiant floor cooling system transports water through the system which absorbs all the heat loads generated in the system making the overall temperature in the system under control. The only mode of electric power used in radiant cooling system is to run pump for supplying water to the system.

Thermoelectric generation is the latest trend used worldwide to generate electricity. A thermoelectric power generator directly converts thermal gradient energy (heat) to electric current by following “Seebeck effect”. When two junctions of a thermoelectric module are kept at two different temperature extremities, electrons flow from the higher potential zone to that of lower potential. The movement of charge produces a voltage that can be harnessed and used for supplying electric power to desired sources.

This research houses these two different technologies under one roof. This research aims at providing the source of power for running pump and other devices in radiant cooling system utilizing thermoelectric generator. Test setup is generated considering only under floor cooling technique. The hot potential is provided by giving hot water supply. So, this research proposes and implements a thermoelectric radiant floor cooling system from the hot water supply unit of

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commercial buildings including malls, hotels and educational institutions. The key is to directly convert the heat energy from hot water supply unit to electrical energy using a thermoelectric generator. The cold side potential will be provided by the cold water supply unit of radiant floor cooling system

A. SCOPE OF THE RESEARCH

The major aim of this research is to develop an optimum cooling system working under 100% energy savings. Chiller units in commercial buildings are already required for them to meet hot and cold water requirements. So developing a system to accommodate all the energy needs is a huge success. Cogeneration is the main additive superpower in 21st century. This research also tries to close the idea of radiant cooling system which is the most energy efficient cooling techniques now available in the market and thermoelectric generation which is the most silent, energy effective way of producing electric current to generate the most energy efficient technique for cooling utilizing maximum energy savings. This research checks out the variation of amount of electric power generated by TEG for different conditions of radiant floor cooling system.

B. OBJECTIVES OF THE RESEARCH

The objectives of this research are as follows:

- Develop the most suitable design to place thermoelectric generator without affecting radiant floor cooling system.
- Generate a cooling load calculation for a typical room and design the radiant floor cooling system with materials available in India.
- Develop an experimental setup for testing the radiant floor cooling condition and calculate the net voltage produced for temperature difference considered.
- Comparison of heat transfer performance of 1.5 cm and 2.54 cm diameter copper pipes for maximum and minimum temperature difference between surface temperature and radiant pipe temperature.
- Generate a typical model as on experimental setup on Creo parameteric software and analyze the test condition in Ansys 14.5 software.
- Calculate the net voltage, current and power produced by the thermoelectric generator with the hot and temperature potential developed through the new design. And compare the above mentioned parameters for 1.25 cm and 2.54 cm diameter pipes.

II. MATERIALS USED

A. RADIANT COPPER PIPE

Copper pipe of diameters 1.25 cm of thickness 1.6 mm and 2.54 cm of 2.2mm, each of length 30 cm are considered for preparation of radiant panel under floor. A copper pipe is welded with rectangular copper bar of height 3 mm, width 2 cm, length 30 cm for placing thermoelectric generator in position. Copper pipe was selected because of its easy availability and high thermal conductivity. It could sustain heavy loads from outside once it goes under floor slab.



Fig.1: 1.25 cm diameter copper pipe welded with rectangular bar

Fig. 1 shows 1.25 cm diameter copper pipes of thickness 1.6 mm and of length 30 cm welded with rectangular copper bar of 3 mm height, 2 cm thickness and 30 cm length.

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Fig.2: 2.54 cm diameter copper pipe welded with rectangular bar

Fig. 2 shows 2.54 cm diameter copper pipes of thickness 2.2 mm and of length 30 cm welded with rectangular copper bar of 3 mm height, 2 cm thickness and 30 cm length

B. THERMOELECTRIC MODULE

Thermoelectric module is the device which continuously produces electric current when a thermal potential difference is provided on both sides of thermoelectric generator. It follows the principle of Seebeck effect. By considering the operating temperature difference for our research the selected thermoelectric generator is TEC1-12706 model thermoelectric generator.

Specification of TEC1-12706 is provided below

Voltage	: 12 volt D.C
Current	: 1.5 A
Material	: Silicon Semiconductor
Size	: 40 x 40 x 5 mm
Temp difference	: 10 ⁰ C to 90 ⁰ C



Fig.3: TEC1-12706 thermoelectric module

Fig. 3 shows picture of TEC1-12706 Thermoelectric module used in this project. Three thermoelectric modules are connected in series in the experiment test rig.

III. MATHEMATICAL CALCULATION

The room considered for radiant floor cooling system to be applied is 9m x 9m x 3m classroom with 1 teacher and 29 students.

No external cooling loads for room are considered and only available internal cooling loads are due to occupants. Fresh air flow rate considered is 34m³/h per person (ASHRAE standard). All the readings in calculations are in SI units.

Aim of radiant cooling system is to maintain space temperature for occupants at 23 DBT and 50% RH.

Total internal loads considered are only due to occupants. Heat load from occupants include both sensible and latent heat gain.

$$Q_s = \text{Number of occupants} \times \text{SHG}$$
$$Q_L = \text{Number of occupants} \times \text{LHG}$$
$$Q_T = \text{Number of occupants} \times \text{THG}$$

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Q_s = Sensible heat generated by occupants

Q_L = Latent heat generated by occupants.

Q_T = Total heat generated by occupants

SHG = Sensible heat gain.

LHG = Latent heat gain.

THG = Total heat gain.

For teacher total heat gain is 175W and for student 100W. (ASHRAE standard specified) [4].

Sensible heat gain = Total heat gain x Sensible heat gain factor

For teacher,

$$\text{Sensible heat gain} = 175 \times 0.5 = 87.5 \text{ W}$$

For student,

$$\text{Sensible heat gain} = 100 \times 0.65 = 65 \text{ W}$$

$$Q_s = 29 \times 65 + 1 \times 87.5 = 1827.5 \text{ W}$$

$$Q_L = 29 \times 35 + 1 \times 87.5 = 1102.5 \text{ W}$$

$$\text{Total heat generated, } Q_T = 29 \times 100 + 175 = 3075 \text{ W}$$

In practical cases some more heat is generated due to air resistances and some other factors, so a safety factor of 1.25 is provided for optimum cooling.

$$Q_T = 3075 \times 1.25 = 4205 \text{ W}$$

Converting the heat gain in terms of tonnage value,

$$\text{We get, } 4205/3500 = 1.2 \text{ TR is required.}$$

Using 100% outdoor supply per person of 34m³/h(20 CFM) (ASHRAE standard fresh air supply per person for thermal comfort and cooling) [4].

The ventilation flow rate for 30 persons

$$V_a = 30 \times 34 = 1020 \text{ m}^3/\text{h.}$$

Ventilation flow rate for 30 persons per second

$$V_a = 1020/3600 = 0.283 \text{ m}^3/\text{s.}$$

For 30 persons, the humidity ratio due to ventilation for occupant latent heat load. (humidity ratio always affect latent heat load)

$$Q_L = \text{Latent heat of vapourisation of water} \times \text{air flow rate} \times \text{density of air} \times \text{humidity ratio}$$

$$= L_v \times V_a \times \rho \times \omega$$

[validation of equation using SI unit checks $W = J/Kg \times m^3/s \times Kg/m^3 = J/s$]

$$Q_L = 1102.5 = 333.5 \times 10^3 \times 0.283 \times 1.2 \times \omega$$

Now,

$\omega = 0.009735 \text{ Kg of H}_2\text{O/ Kg of dry air}$, represents humidity ratio/ mixing ratio for 30 people.

At 23°C and 50% RH dew point temperature is 12.032 °C and dew point temperature at ω for 23°C is 13.568°C and RH is 55.295%.

Minimum allowable surface temperature of radiant panel is usually 1°C to 1.5°C above dew point temperature.

$$T_p = 13.568^\circ\text{C} + 1^\circ\text{C} = 14.568^\circ\text{C} \text{ or } 13.568^\circ\text{C} + 1.5 = 15.068^\circ\text{C.}$$

Now 14.568°C to 15.068°C represents lowest allowable panel surface temperature to avoid surface condensation.

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Now to find out sensible air capacity of air, designer choice of temperature is always 1 °C more than atmospheric dew point temperature of air with the specified constraint. The problem statement is to maintain space temperature at 23°C and 50% RH. So at 23°C and 50% RH the corresponding dew point temperature is

$$12.032^{\circ}\text{C} + 1^{\circ}\text{C} = 13.032^{\circ}\text{C}.$$

Then sensible air capacity,

$$\begin{aligned} Q_{\text{Sair}} &= \text{Density of air} \times \text{Air flow rate} \times \text{Specific heat at constant volume} \times \Delta T \\ &= 1.2 \times 0.283 \times 787 \times (23-13) \\ &= 2672.5 \text{ W} \end{aligned}$$

$$\begin{aligned} Q_{\text{flux}} &= Q_{\text{Spanel}} / \text{Area available for setting panel.} \\ &= 1532.5 / (9 \times 9) = 1532.5 / 81 = 18.919 \text{ W/m}^2. \end{aligned}$$

Then surface temperature of radiant floor will be

$$\begin{aligned} T_s &= T_{\text{amb}} - (Q_{\text{flux}}/H) \quad [\text{from equation of heat convection } Q_{\text{flux}} = HA (T_{\text{amb}} - T_s)] \\ &= 23 - (18.919/7) = 20.3^{\circ}\text{C} \end{aligned}$$

H = Space heat exchange coefficient for air in W/m²°C

Since 20.3°C is above occupied dew point temperature of 14.568°C and 19°C which is acceptable safety margin temperature, the radiant floor cooling system can be accepted for air cooling process. So minimum surface temperature for cooling must be 19°C and maximum must be below 20.3°C for optimum cooling effect for occupants

IV. DESIGN AND EXPERIMENTAL SETUP

Normally, the floor slab thickness in India varies from 10 cm to 20 cm for residential and commercial buildings. The floor slab designed in this project is of overall thickness 20cm and two floor slab materials are used. The top portion is concrete slab with 5cm thickness and bottom portion is polystyrene slab of 15 cm thickness. Two different materials are used for floor design to accommodate hot and cold water supply through copper pipe. Thermal conductivity of copper pipe, concrete slab, polystyrene slab are 401 W m⁻¹K⁻¹, 0.72 W m⁻¹K⁻¹ and 0.033 W m⁻¹K⁻¹ respectively. The concrete slab accommodates the copper pipe with cold water and polystyrene slab accommodates the copper pipe with hot water. The length and width of slab are 30 cm x 30 cm. The same design is followed for both 1.25 cm diameter copper pipes and 2.54 cm diameter copper pipes, since heat flux through both remains almost same. So thermal analysis of 1.25 cm diameter pipe is only done on ANSYS 14.5. The cold water pipe is provided at a height of 5cm from top surface. Two designs are made practically for testing. One design accommodating two 1.25cm diameter pipes for hot and cold water supply and other accommodating two 2.54 cm diameter pipes for hot and cold water supply.

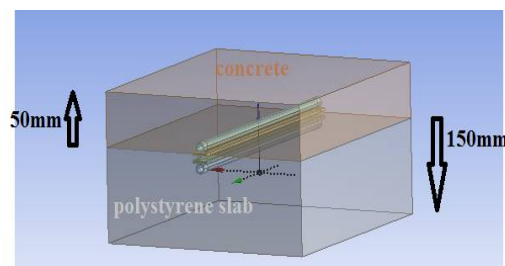


Fig.4: 3D view of floor slab design

Fig. 4 shows isometric view of the floor slab designed for the experimental investigation. The designing is done on Creo parametric software.

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Thermoelectric generator is placed in between two rectangular bars welded with the copper pipes. Rectangular bars are welded to increase the contact area with thermoelectric generator. Three TEG's (TEC1-12706) connected in series is placed between two copper pipes. For making 100% contact of TEG with pipe, each pipe is welded with a rectangular copper bar of 3 mm gauge and TEG is placed in between the copper bars which are bolted (in 1.25cm diameter pipe) or clamped (in 2.54cm diameter pipe).



Fig.5: TEC1-12706 placed between 1.25 cm diameter pipes

Figs. 5, 6 shows three thermoelectric modules TEC1-12706 placed between two rectangular copper bar of 3mm height, 2cm thickness and 30 cm length for each 1.25cm diameter copper pipes of thickness 1.6cm and of length 30cm and 2.54 cm diameter copper pipes of thickness 1.6cm and of length 30cm respectively.



Fig.6: TEC1-12706 placed between 2.54cm diameter pipes

Fig. 7 shows the prototype of 30 cm x 20 cm x 20 cm concrete block and polystyrene slab which is developed which encases two copper pipes each of diameter 1.25 cm. The floor slab designed is manufactured according to the specified dimensions



Fig.7: Test apparatus

Fig. 8 shows the experimental setup developed. The cold water line at top is connected to evaporator of refrigeration test rig and hot water line at bottom is connected to boiler test rig. Cold water is supplied from evaporator of refrigeration test rig at constant temperature of 15⁰C and hot water is supplied from Boiler test rig at higher temperatures required. Wires extending from thermoelectric generators are connected to multimeter. The apparatus for testing the current generated from radiant floor cooling system is of dimension 30 x 20 x 20 cm concrete and

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polystyrene block. Two copper pipes welded with rectangular bar copper pieces respectively to hold thermoelectric in centre is enclosed in concrete block. To provide tight holdness, clamps are used.



Fig.8: Experimental test rig

V. RESULT AND DISCUSSION

For the test apparatus developed, the result obtained from the ANSYS 14.5, steady state thermal analysis is shown in Fig. 9. The cold water inlet temperature is 15°C and hot water inlet temperature is 65°C. 65°C is the optimum hot water temperature for plumbing purpose in commercial buildings. The temperature difference between hot and cold water supply line is 50°C. The surface temperature obtained is 20°C.

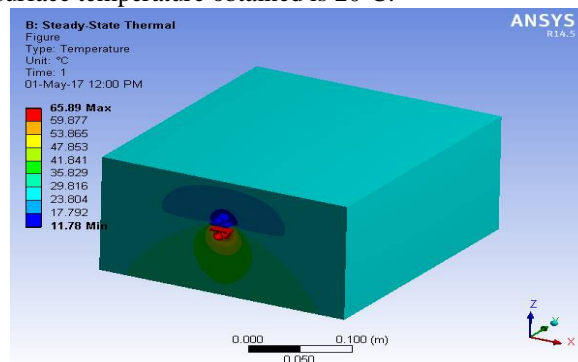


Fig.9: Temperature variation for prescribed slab for steady state thermal analysis.

Similar results will be obtained for 2.54 cm diameter pipes since only varying parameter is gauge thickness.

Fig.10 shows the comparison of voltage produced for 1.25 cm and 2.54 cm diameter pipes for different temperature differences

Fig.11 shows the comparison of current produced for 1.25 cm and 2.54 cm diameter pipes for different temperature differences

Fig.12 shows the comparison of power produced for 1.25 cm and 2.54 cm diameter pipes for different temperature differences.

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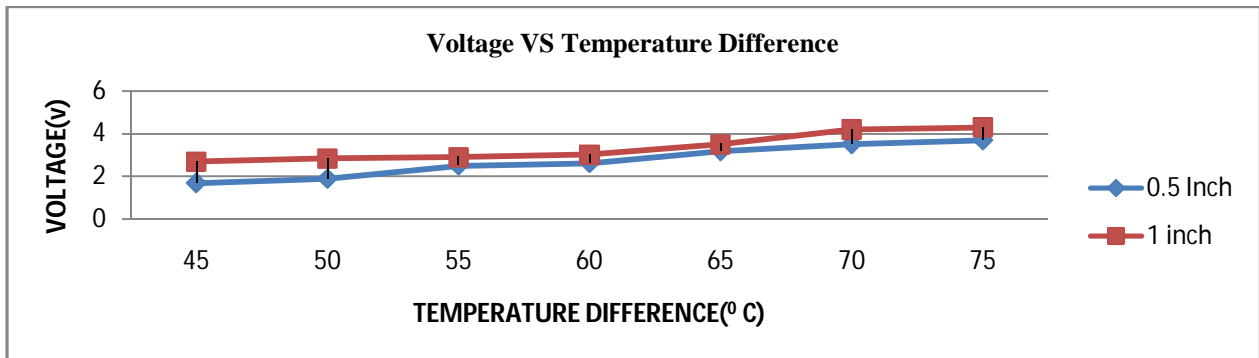


Fig.10: Variation of voltage with temperature difference.

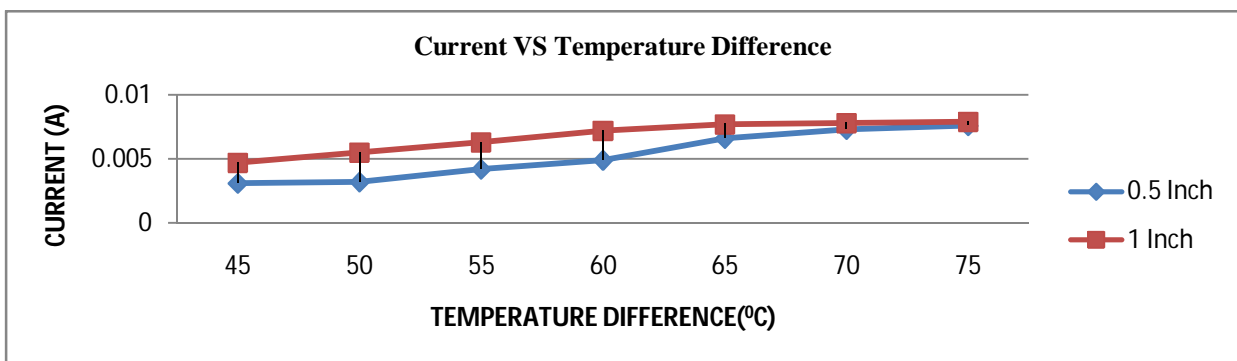


Fig.11. Variation of current generated with temperature difference.

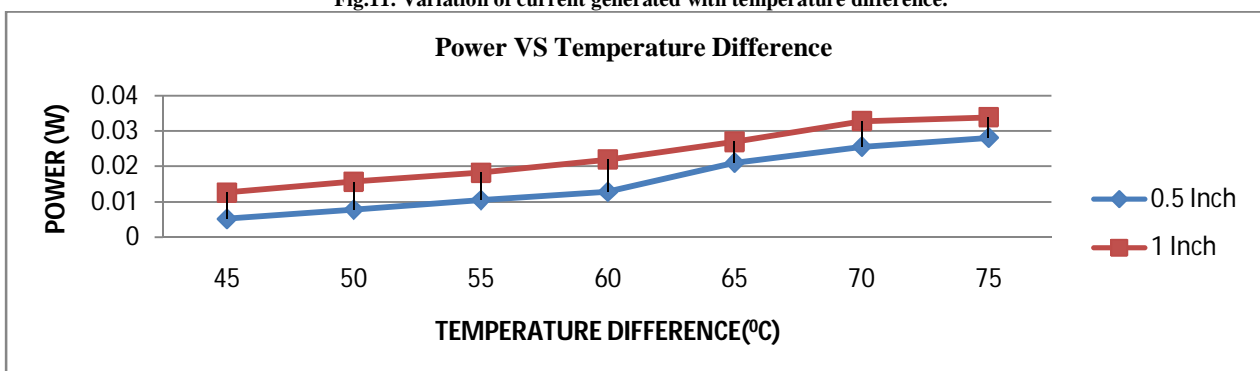


Fig.12. Variation of electrical power developed with temperature difference.

VI. CONCLUSION

From three thermoelectric generators connected in series an output voltage of 1.9V was obtained when temperature difference was maintained at 50°C. By applying test result obtained from experimental setup into the problem statement of room, the net voltage produced from the apparatus can be obtained. In a pipe of 9m length 200 thermoelectric modules can be provided. A room of 9m x 9m could accommodate 30 pipes of 9 m length. So a total of 6000 thermoelectric modules can be provided. If all the thermoelectric modules are connected in series, then a maximum of 3.8 KV of voltage can be obtained. The desired temperature of 20°C is obtained on the surface. So from

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this analysis it is clear that by proper arrangement of thermoelectric generators output voltage can be varied and controlled and can be used to run the mechanical devices without power failure. This way, energy efficiency of radiant cooling system can be improved to its peak value.

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BIOGRAPHY



Mr. Harikrishnan. B graduated from College of Engineering and Management, Punnappra with a Bachelor of Technology (Hons) Kerala University in Mechanical Engineering in 2015. Presently pursuing M.Tech in thermal engineering from Malabar College of Engineering and Technology, Thrissur under Dr. APJ Abdul Kalam Technological University, Kerala



Mr. Sathil. P. T is working as Assistant professor in Mechanical Engineering at Malabar College of Engineering and Technology, Thrissur. Graduated B.Tech from Jyothi Engineering College, Thrissur. Post graduated from Government Engineering College, Thrissur.