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Research Article

Design and Analysis of Radiant Cooling System.

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ABSTRACT

Radiant cooling slabs are an innovative system used in buildings for cooling purposes. Similar to radiant heating, which uses heated surfaces to warm spaces, radiant cooling involves using chilled surfaces to remove heat from a room.
Temperature is one of the important loads for designing slab track. The characteristic of slab track temperature varies greatly with different regional climates. In this work, 4 different grade of slab track model was built with the radiant cooling system under outdoor conditions the statistical characteristic of temperature gradient in slab and with and without radiant cooling system is tested.
Slab with grade M20, M25, M30 and M40 are constructed and for cooling, the copper pips of dia. 8mm and 5mm are embedded in slab at the bottom part of the slab.
By analysing the data is found that thermal conductivity of the concrete increase with the grade. Therefore, the radiant cooling system will work more efficiently in lower grade like M20 and M25.

Keywords: Concrete, cooling capacity, Radiant cooling, Copper pipes, Energy saving, slab.

1. Introduction

The International Energy Agency (IEA) predicted in its most recent World Energy Outlook that India's electricity demand for home air conditioners will climb nine times by 2050, exceeding the continent's current total power consumption. Over the next thirty years, India will continue to have the largest increase in energy demand globally, according to IEA predictions. Under the proposed measures, India's estimated energy supply is predicted to increase from 42 exajoules (EJ) in 2022 to 53.7 EJ in 2030 and then to 73 EJ in 2050. Should declared commitments be considered, the supply may attain 47.6 EJ by 2030 and 60.3 EJ by 2050.
Radiant cooling (RC) systems are gaining traction as an alternative to traditional air-conditioning systems due to their energy-saving potential and ability to provide higher thermal comfort and indoor air quality (IAQ). These systems have seen increased adoption in various building types such as offices and airports because of their reduced energy consumption and improved thermal comfort.
High-efficiency heating and cooling systems are required to provide indoor thermal comfort while utilizing the least amount of energy in order to achieve sustainable development. In comparison to air-based cooling systems, radiant cooling systems have shown great energy-saving potential, which has contributed to their increasing popularity in recent decades. There are still issues, though, particularly with making sure these systems use the least amount of energy possible for rapid indoor thermal comfort. Thermally activated building systems (TABS), water-based embedded surface cooling systems (ESCS), and radiant cooling panels (RCP) are the three main categories of radiant cooling systems.
The efficient operation of these systems depends on managing the radiant cooling load (the heat removed by the hydronic system per unit time) and cooling capacity (the heat absorbed by cooling surfaces per unit time). The dynamics of heat transfer on these surfaces might not always align with the heat removed by internal water systems due to the surrounding thermal mass.
Radiant cooling systems are not just integral to building construction but can also function as terminal equipment. They enhance radiant heat exchange between surfaces and rooms, altering a building's thermal

inertia and heat storage/release processes. Additionally, these systems can actively regulate temperature and heat exchange by adjusting water temperature or flow rate.
In order to decrease energy consumption and carbon emissions while increasing indoor comfort and air quality, recent research has concentrated on integrating radiant cooling systems with passive structures. To optimize their potential, radiant cooling systems require a greater understanding of their operation dynamics, which is why effective control approaches are currently being explored conceptually.

2. Materials and Methods

2.1 Copper Tubes

Two copper tubes are used in the slabs with different diameter. One tube is of 8mm and other one is of 5mm dia. 5mm dia. Tube is used to cover the area left by 8mm dia. Tube.
The copper tubes are selected for the system as copper is a good conductor and also durable.
In the place of copper any other type of tubes can be used like plastic.
These copper pipes are placed in the bottom part of slab as it will decrease the distance of the tubes with surrounding and as tubes are placed in the clear cover, the strength of slab will remain same.
The distance between one 8mm dia. Pipe to another 8mm dia. pipe is kept 300mm c/c. so, the distance between one 8mm dia. Pipe with other 5mm dia. Pipe will be 150 mm c/c.

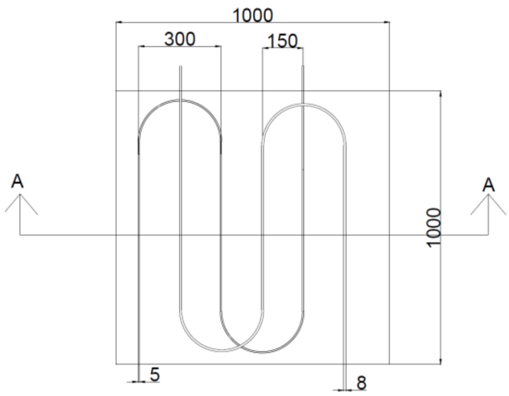

Figure 1: Copper pipes alignment (all dimension in mm)

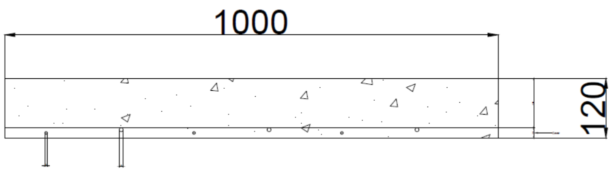

Figure 2: section A-A of slab (all dimension in mm)

2.2 Reinforcement Bars

10 mm dia. bars are used in the slab in order to provide the strength to the slab so that it can be moved while testing.
The dia. of both main bar and distribution bar are kept 10mm.
Total 12 bars are used in one slab of dimension 1000mm x 1000mm
The spacing between the bars is kept 152.4 mm.
Binding wire is used to keep the bars in the right place.

2.3 Concrete

Four slabs are constructed with different grades. The dimension of the slab is kept 1000mmx1000mm, the depth of slab is kept 120mm.
For each slab the quantity of concrete is calculated and the slab is casted with 20mm cover.
M20, M25, M30 and M40 grade of concrete is used.

Table 2.3.1 Quantity of cement, Fine Aggregate and course Aggregates

S. No	Grade	Cement (kg)	Fine Aggregate (kg)	Course Aggregate (kg)
1	M20	52.36	78.54	157.09
2	M25	72	72	144
3	M30	88.61	66.46	132.92
4	M40	96	64.32	127.68

3. Methodology

For the testing, four specimens are created and in each slab copper pipes are placed at a distance of 150mm. A wooden mould of dimension 1000mmx1000mmx120mm was created and the concrete was made according to the calculations and the slab is casted.
The de shuttering of the slab was done and Curing of the slab was done for 7 days.
After 14 days the testing of the slab was done, for testing a heater was placed on the top side of the slab and two thermometers was placed on the both sides.
The heater was turned on and the reading of the top side and bottom side temperature was noted with respect to the time now this testing was done two times, first time with system off and then with system on.
The chilled water was flowed in the copper pipes with the help of a water pump.
The chilled water will carry the heat away from the slab and hence the surrounding temperature will decrease.

Figure 3: Temperature testing with two Thermometer

Figure 4: water flowing through slab by a pump.

4. Experimental Data

4.1 For M20 grade slab

The slab which is casted with M20 grade concrete was tested for temperature gradient and the top surface and bottom surface temperature is noted with respect to the time.

Table 4.1. Change in Bottom surface Temperature and Top surface temperature with respect to time in normal temperature.

S No.	Time in seconds	Top surface temperature (degree c)	Bottom surface temperature
1	0	43.9	39.3
2	15	44.2	39.5
3	30	46.1	39.6
4	45	46.8	39.6
5	60	47.8	39.6
6	75	48.3	39.6
7	90	48.9	39.6
8	105	48.9	39.6
9	120	48.6	39.6
10	135	49.9	39.7
11	150	48.9	39.6
12	180	48.9	39.8
13	210	48.9	38.9
14	240	48.8	39.8
15	270	48.8	39.8
16	300	48.9	39.9
17	330	49.7	39.9
18	360	49.8	40
19	390	49.6	40
20	420	49.8	40.1
21	450	50.9	40
22	480	51.3	40.1
23	510	52.8	40.1
24	540	53.3	40.2
25	570	52.1	40.3
26	600	50.2	40.4
27	630	49.6	40.5
28	660	51.4	40.5
29	690	53.4	40.5
30	720	55.3	40.8
31	750	55.9	40.9
32	810	56.3	40.9
33	870	56.1	41
34	930	57.9	41.1
35	990	57.6	41.1
36	1050	55.8	41.8
37	1110	55.9	42.1
38	1170	57.4	42.4
39	1230	58.1	42.8
40	1290	60.4	43.4

Table 4.1.2 Change in Bottom surface Temperature and Top surface temperature with respect to time with radiant cooling system.

S No.	Time in (s)	Top surface temperature(degree c)	Bottom surface temperature with system on	water temperature
1	0	43.2	37.2	12
2	15	43.3	37.2	12
3	30	43.5	37.2	12.1
4	45	43.7	37.1	12.3
5	60	43.9	37.1	12.2
6	75	44.3	36.9	12.4
7	90	44.9	36.6	12.5
8	105	45.2	36.6	12.7
9	120	45.5	36.3	12.8
10	135	45.9	36.3	12.8
11	150	46.1	36.2	12.8
12	180	46.6	35.8	12.9
13	210	46.9	35.4	12.9
14	240	47.3	35.1	13
15	270	47.8	34.7	13.1

16	300	48.2	34.5	13.3
17	330	48.8	34.1	13.2
18	360	48.8	33.7	13.5
19	390	48.9	33.4	13.2
20	420	49.2	33.1	13.5
21	450	49.6	32.8	13.6
22	480	50.1	32.5	13.8
23	510	50.4	32.2	13.9
24	540	50.8	32	13.9
25	570	51.1	31.8	14.1
26	600	51.5	31.6	14.3
27	630	51.8	31.3	14.4
28	660	51.9	31.1	14.4
29	690	52.4	30.9	14.8
30	720	52.8	30.8	15.1
31	750	53.1	30.6	15.4
32	810	53.4	30	15.8
33	870	53.9	29.4	15.9
34	930	54.3	28.7	16.1
35	990	54.6	28.3	16.2
36	1050	54.8	27.8	16.5
37	1110	55.2	27.2	16.5
38	1170	55.6	26.4	16.7
39	1230	58.1	25.7	16.8
40	1290	60.4	25.1	17

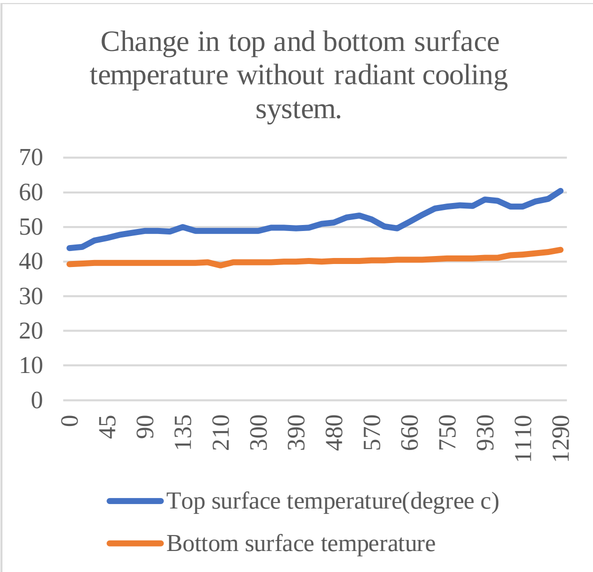

Figure 5: Change in top and bottom surface temperature without radiant cooling system in M20 grade slab.

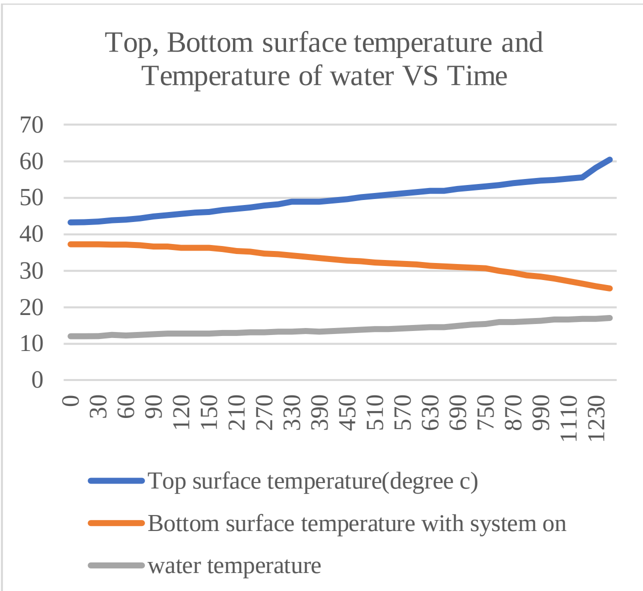

Figure 6: Top, bottom surface temperature and temperature of water VS Time(s) in M20 slab

4.2 For M25 grade slab

The slab was constructed with M25 was tested same as M20 grade of concrete.

Table 4.2.1 Change in Bottom surface Temperature and Top surface temperature with respect to time in normal temperature.

S No.	Time in seconds	Top surface temperature (degree c)	Bottom surface temperature
1	0	42.3	37.9
2	15	43.1	37.9
3	30	44.5	38
4	45	44.9	39.6
5	60	45.3	39.9
6	75	46.1	40.2
7	90	46.8	40.2
8	105	47.1	40.3
9	120	47.3	40.2
10	135	47.5	40.1
11	150	47.8	39.8
12	180	48.1	40.2
13	210	48.6	40.2
14	240	48.9	40.4
15	270	49.4	40.7
16	300	49.9	40.7
17	330	50.3	40.8
18	360	50.4	40.7
19	390	50.9	40.8
20	420	51.4	40.9
21	450	51.7	41.2
22	480	51.9	41.3
23	510	52.3	41.3
24	540	52.5	41.4
25	570	52.8	41.3
26	600	52.9	41.4
27	630	53.1	41.4
28	660	53.4	41.5
29	690	53.7	41.5
30	720	53.9	41.6
31	750	54.2	41.6
32	810	54.6	41.7
33	870	54.9	41.9
34	930	55.3	41.9
35	990	55.9	42.1
36	1050	56.4	42.1
37	1110	57.2	42.4
38	1170	57.5	42.9
39	1230	58.4	43.8
40	1290	59.9	44.2

Table 4.2.2 Change in Bottom surface Temperature and Top surface temperature with respect to time with radiant cooling system.

Time in seconds	Top surface temperature (degree c)	Bottom surface temperature	Time in seconds
0	42.1	36.2	0
15	42.4	36.2	15
30	42.8	36.2	30
45	43	36.1	45
60	43.2	36.1	60
75	43.4	36.1	75
90	43.8	35.9	90
105	44.1	35.9	105
120	44.4	35.9	120
135	44.6	35.7	135
150	44.8	35.6	150
180	45.2	35.6	180
210	45.7	35.5	210
240	45.9	35.4	240
270	46.3	35.4	270
300	46.6	35.3	300
330	46.9	35.3	330
360	50.4	35.2	360
390	50.8	35	390
420	51.1	34.9	420

450	51.4	34.9	450
480	51.9	34.5	480
510	52.3	34.3	510
540	52.5	34.1	540
570	52.9	33.8	570
600	53.5	33.4	600
630	53.9	33	630
660	54.2	32.5	660
690	55.5	31	690
720	55.7	29.9	720
750	56.2	29.5	750
810	56.9	29.2	810
870	57.2	28.7	870
930	57.5	28.3	930
990	58.1	27.5	990
1050	58.2	27.2	1050
1110	58.6	26.7	1110
1170	58.8	26.9	1170
1230	59	25.9	1230
1290	59.5	25.3	1290

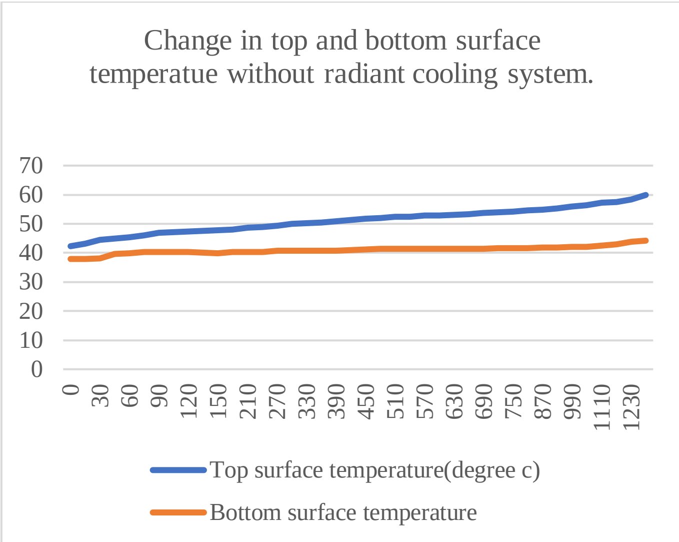

Figure 7: Change in top and bottom surface temperature without radiant cooling system in M25 grade slab.

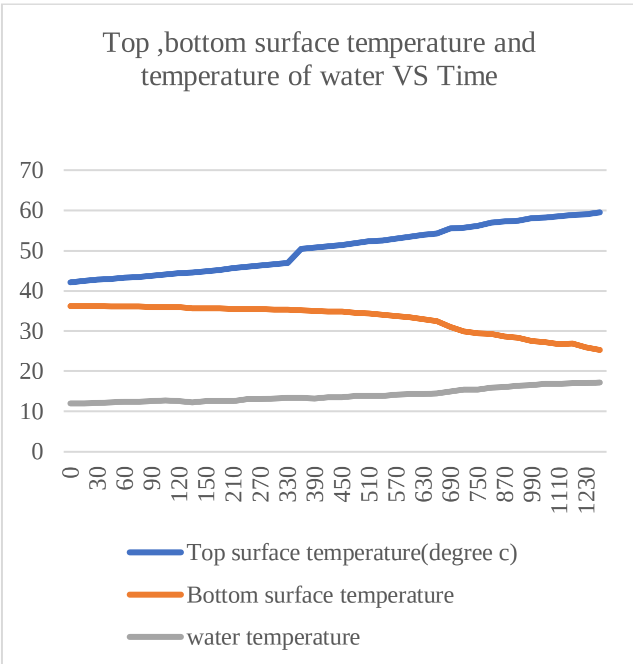

Figure 8: Top, bottom surface temperature and temperature of water VS Time(s) in M25 slab

4.3 For M30 grade slab

Table 4.3.1 Change in Bottom surface Temperature and Top surface temperature with respect to time in normal temperature.

Time in seconds	Top surface temperature (degree c)	Bottom surface temperature	Time in seconds
0	44.3	38.1	0
15	44.5	38.1	15
30	44.7	38.2	30
45	44.9	39.2	45
60	45.2	39.3	60
75	45.4	39.5	75
90	45.8	39.4	90
105	46.1	39.6	105
120	46.4	39.6	120
135	46.5	39.8	135
150	46.8	39.8	150
180	47.3	40	180
210	47.7	40	210
240	47.9	40.1	240
270	48.5	40.1	270
300	48.9	40.2	300
330	49.2	40.2	330
360	49.7	40.2	360
390	49.9	40.3	390
420	50.4	40.5	420
450	50.7	40.6	450
480	50.9	40.8	480
510	51.4	40.7	510
540	51.8	40.9	540
570	52.2	41.2	570
600	52.6	41.2	600
630	52.9	41.3	630
660	53.3	41.5	660
690	53.7	41.7	690
720	53.9	41.6	720
750	54.2	41.8	750
810	54.9	42.1	810
870	55.2	42.3	870
930	55.3	42.5	930
990	55.6	42.9	990
1050	57.3	43.6	1050
1110	57.6	43.6	1110
1170	57.5	43.9	1170
1230	58.4	44.4	1230
1290	59.9	45.2	1290

Table 4.3.2 Change in Bottom surface Temperature and Top surface temperature with respect to time with radiant cooling system.

Time in seconds	Top surface temperature (degree c)	Bottom surface temperature	water temperature
0	43.3	36.3	12
15	43.4	36.2	12
30	43.6	36.1	12.2
45	44	36.1	12.4
60	44.4	35.8	12.5
75	44.8	35.9	12.5
90	45.1	35.7	12.6
105	45.3	35.7	12.6
120	45.6	35.6	12.8
135	45.9	35.4	12.7
150	46.1	35.3	12.6
180	46.5	35.1	12.8
210	46.7	34.9	12.9
240	46.9	34.9	13.3
270	47.4	34.7	13.4
300	47.9	34.7	13.5
330	48.3	34.6	13.5
360	48.9	34.6	13.4
390	49.3	34.5	13.7
420	49.6	34.2	14.1
450	50.1	33.9	14.3
480	50.4	33.77	14.4
510	50.6	33.5	14.6

540	50.9	33.2	14.7
570	51.4	32.8	14.8
600	51.7	32.8	15.2
630	51.9	32.7	15.5
660	52.5	32.5	15.6
690	52.7	32.4	15.7
720	52.9	31.9	16
750	53.3	31.2	16.2
810	53.6	30.8	16.5
870	53.8	29.9	16.5
930	54.3	29.6	16.7
990	55.3	29.1	16.8
1050	55.6	28.8	16.9
1110	55.9	28.5	17
1170	56.7	28.2	17.3
1230	57.3	27.8	17.5
1290	57.9	27.3	17.9

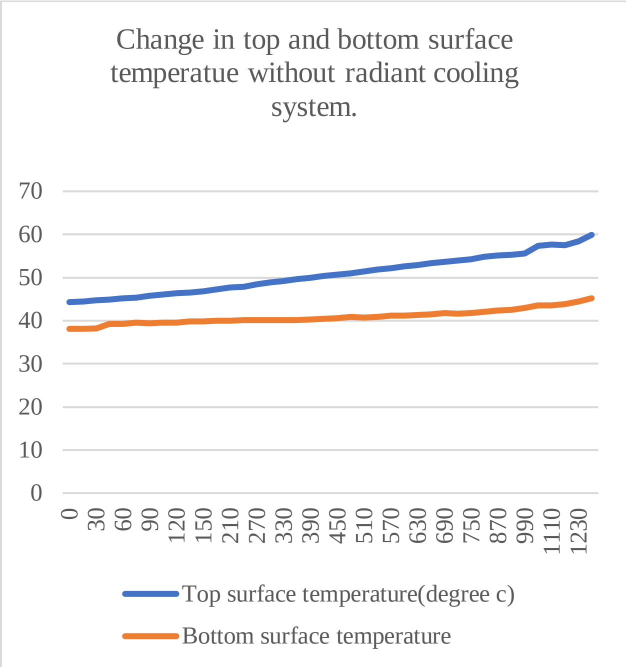

Figure 9: Change in top and bottom surface temperature without radiant cooling system in M35 grade slab.

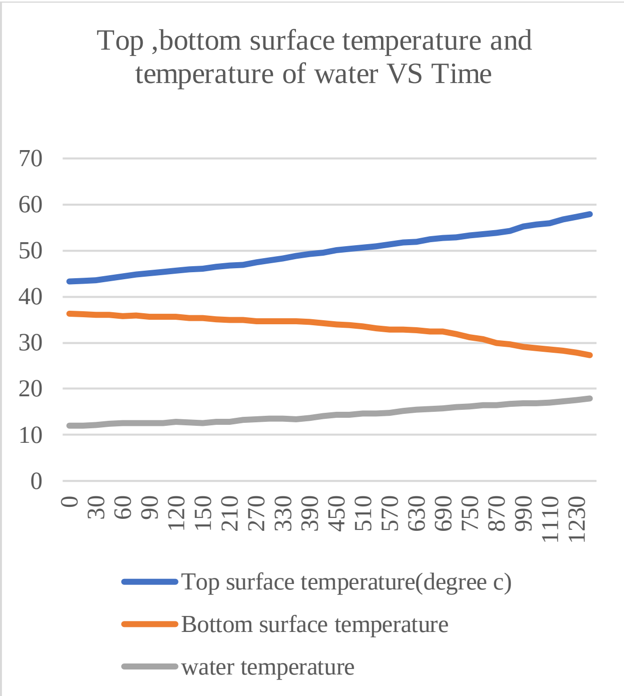

Figure 10: Top, bottom surface temperature and temperature of water VS Time(s) in M35 slab

4.4 For M40 grade slab

Table 4.4.1 Change in Bottom surface Temperature and Top surface temperature with respect to time in normal temperature.

S No	Time in seconds	Top surface temperature(degree c)	Bottom surface temperature
1	0	40.3	38.3
2	15	40.9	38.6
3	30	44.1	38.7
4	45	44.3	38.9
5	60	44.6	39.4
6	75	45.2	39.6
7	90	45.5	39.8
8	105	45.6	40
9	120	45.8	40.2
10	135	46.1	41.5
11	150	46.3	42.6
12	180	46.5	40.7
13	210	46.8	41.4
14	240	47.2	43.8
15	270	47.5	43.8
16	300	47.9	43.9
17	330	48.1	43.9
18	360	48.3	44.1
19	390	48.5	44.2
20	420	48.7	44.5
21	450	49.2	44.6
22	480	49.6	44.6
23	510	49.8	44.7
24	540	50.2	44.6
25	570	50.5	44.7
26	600	50.8	44.7
27	630	51.3	44.7
28	660	51.7	44.9
29	690	52.3	45.2
30	720	52.5	45.4
31	750	53.2	45.4
32	810	53.7	45.7
33	870	54.2	46.2
34	930	54.9	46.5
35	990	55.6	46.6
36	1050	56.4	46.7
37	1110	57.2	47.2
38	1170	57.7	47.7
39	1230	59.3	48.1
40	1290	60.1	48.3

Table 4.4.2 Change in Bottom surface Temperature and Top surface temperature with respect to time with radiant cooling system.

Time in seconds	Top surface temperature (degree c)	Bottom surface temperature	water temperature
0	40.1	36.3	12
15	40.2	36.2	12.2
30	40.5	35	12.5
45	41.2	35.8	12.5
60	41.7	35.8	12.6
75	42.4	35.7	12.6
90	42.8	35.6	12.8
105	43.7	35.4	12.9
120	44.3	35.2	12.7
135	44.7	35.1	12.7
150	44.9	34.9	12.9
180	45.4	34.5	13
210	45.6	34.5	13.3
240	45.8	34.5	13.4
270	45.9	34.4	13.4
300	46.2	34.3	13.5
330	46.5	34.1	13.6
360	46.7	33.8	13.8
390	46.9	33.9	13.8
420	47.5	33.7	14.1
450	47.8	33.7	14.2
480	48.3	33.7	14.3

510	48.5	33.5	14.5
540	48.7	33.5	14.6
570	48.9	33.4	14.6
600	50.2	33.4	14.8
630	50.4	33.2	14.9
660	50.8	33.1	15
690	51.3	32.8	15.5
720	51.6	32.5	16.1
750	51.9	32.4	16.5
810	52.4	32.2	16.8
870	52.7	31.7	17.3
930	52.9	31.5	17.5
990	53.4	31.2	17.9
1050	54.7	30.8	18
1110	56.2	30.5	18.1
1170	56.7	30.2	18.2
1230	57.3	29.6	18.4

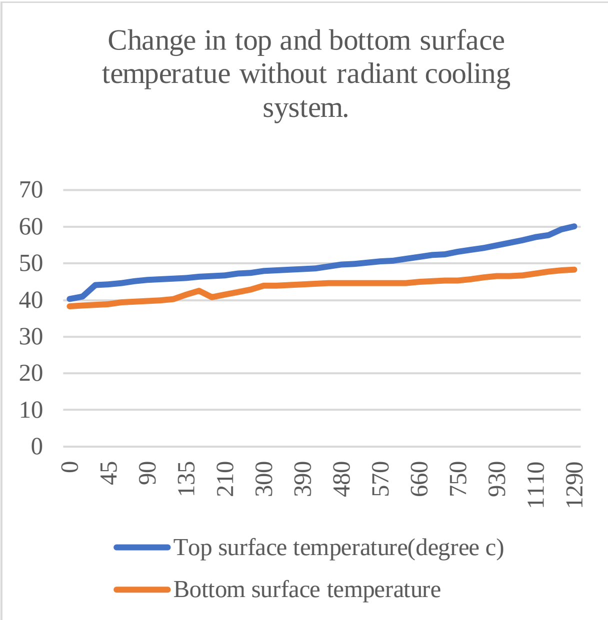

Figure 11: Change in top and bottom surface temperature without radiant cooling system in M40 grade slab.

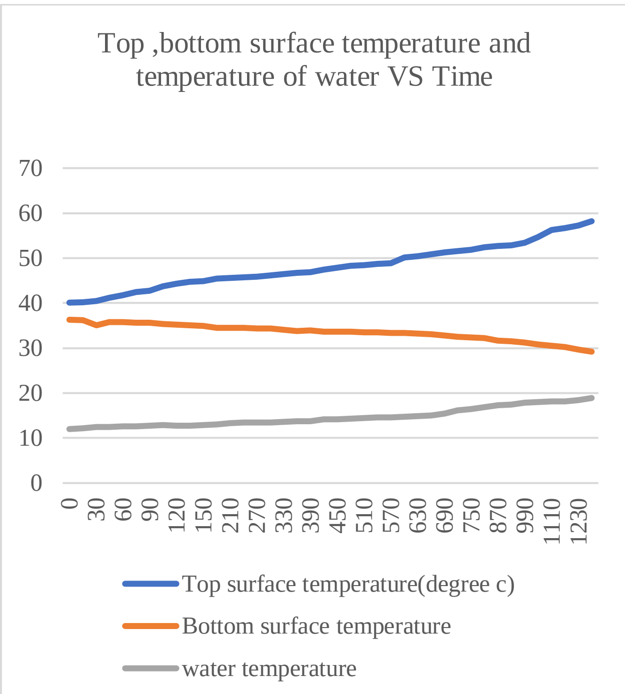

Figure 12: Top, bottom surface temperature and temperature of water VS Time(s) in M40 slab

5. Conclusion

By analysing the data collected by the experimental studies it is found that the thermal conductivity of the concrete increases with the grade of concrete.

It is found that the radiant cooling system works efficiently when the grade of concrete is M20 or M25.

But due its less power consumption property, it can be used in all type of slab.

By placing the pipes in the cover the cooling capacity of the system increases as the distance between the surrounding and pipes decreases.

Using two dia. Pipes, cover the area effectively and the cooling capacity increases.

In M20 grade concrete slab the temperature change were found maximum as due to low thermal conductivity of the M20 grade of concrete the less heat is travelled though the slab and the radiant cooling system work effectively.

In M20 grade concrete slab the bottom temperature in normal slab were 42.2°C and with radiant cooling system it decreases to 23.4°C after the continuous heating the top surface with the help of a heater for 21.5 minutes.

The temperature difference between top and bottom surface were found 17°C without radiant cooling system.

With radiant cooling system the temperature difference was 34.9°C. due to this temperature difference the surrounding temperature will decrease significantly.

In M25 grade concrete slab, the bottom temperature of the slab was 44.2°C and with radiant cooling system the bottom temperature of the slab decrease to 25.3°C. The temperature difference between top and bottom surface were found s15.7°C without radiant cooling system. With radiant cooling system the temperature difference was 34.2°C.

In M30 grade concrete slab, the bottom temperature of the slab was 45.2°C and with radiant cooling system the bottom temperature of the slab decrease to 27.3°C. The temperature difference between top and bottom surface were found 14.7°C without radiant cooling system. With radiant cooling system the temperature difference was 30.6°C.

In M40 grade concrete slab, the bottom temperature of the slab was 48.3°C and with radiant cooling system the bottom temperature of the slab decrease to 29.2°C. The temperature difference between top and bottom surface were found 11.8°C without radiant cooling system. With radiant cooling system the temperature difference was 29°C.

In the place of copper pipe, flexible plastic pipes can also be used. This system required a cooling mechanism or a radiator which will decrease the temperature of water.

In the place of radiator, a different setup can be used in which a secondary coil will be placed in the ground and water will flow though the slab carrying the heat and when it flows though the secondary coil, it will release the heat there as the ground temperature is low as compared to atmospheric temperature. This cycle will continue to work till the system is on.

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