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FACTORS AFFECT THE PERFORMANCE OF RADIANT SYSTEM +

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Abstract :

In radiant cooling system, all the sensible cooling in the space is provided by cooled metal panels or concrete slabs. These panels cool the room surfaces and occupants by absorbing radiant heat.

Radiant cooling systems may be delivered in three ways: ceiling-mounted suspended metal panels, lay-in panels in T-bar ceilings, or tubing embedded in concrete ceilings. Panel systems- either suspended type or T-bar lay-in type are made of steel or aluminum with copper tubing mounted on the backside. The other option is embedded plastic tubing (covered with Plaster) in exposed structural slabs.

The purpose of this study is to investigate the efficiency, radiant plate thickness and pipe spacing on the radiant plate of different types of plate material (Aluminum, steel and Plaster) of radiant ceiling system. Based on the thermodynamic principles, the analysis model of radiant plate is established. The efficiency of radiant plate can be simulated and calculated by the model. Under the different type of radiant plate material (thermal conductivity), thickness of plate and pipe spacing, the efficiency of radiant ceiling and the surface temperature distribution on radiant plate are compared and analyzed.

The conclusions show that radiant plate thickness, thermal conductivity of the plate material and pipe spacing have primary influence on the surface temperature distribution and the efficiency of radiant plate, and the Aluminum plate is the best material used in radiant cooling system because of its high thermal conductivity.

العوامل المؤثرة على أداء منظومة التبريد الشعاعية

عبد الامير عبد الزهرة

المستخلص:

في منظومات السطوح المشعة يتم امتصاص الحرارة المحسوسة (الجافة) من المحيط بواسطة سطوح معدنية أو سقوف كونكريتية مبردة. حيث تقوم هذه السطوح الباردة بامتصاص الحرارة من السطوح الداخلية للغرفة ومحتوياتها الداخلية بطريقة الاشعاع.

هناك ثلاثة انواع من منظومات التبريد المشعة، النوع الأول تكون على شكل ألواح معدنية متدلية من السقف والنوع الثاني منها تكون على شكل ألواح مثبتة على السقف باستخدام حمالات على شكل حرف T، أما النوع الثالث فتكون على شكل

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سقوف كونكريتية مبردة. الألواح المعدنية في النوع الأول والثاني من هذه المنظومات تحتوي على أنابيب من النحاس ملحوم على سطح الخارجي، أما في النوع الثالث من السطوح المبردة فتحتوي على أنابيب بلاستيكية على السقف الكونكريتي للغرفة ومغطاة بطبقة من الجبس.

إن الهدف من البحث هو دراسة ثلاث عوامل تأثر على كفاءة منظومة التبريد المشعة وهي: نوع المادة المستخدمة في السطوح المشعة في المنظومة وسمكها إضافة إلى طريقة توزيع أنابيب التبريد في هذه السطوح. واعتمادا على مبدأ الثرموديناميك تم تحليل ومقارنة استخدام ثلاثة أنواع من المواد (الألمنيوم، الحديد والجبس) في السطوح المشعة وسمكها على كفاءة السطح المشع إضافة إلى تأثير المسافة بين أنابيب التبريد في السطوح المشعة على توزيع درجات الحرارة على السطح.

من خلال البحث تم التوصل إلى أن مادة الألمنيوم هي أفضل مادة يمكن استخدامها في السطوح المشعة لمنظومات التبريد المشعة إضافة إلى تقليل المسافة بين أنابيب التبريد المثبتة على السطح المشع، ولكن كلفة تصنيع السطوح المشعة من الألمنيوم هو العامل المهم في اختيار المادة وتصميم الأنابيب في منظومات التبريد المشعة.

Introduction:

The ceiling radiant cooling panel (CRCP) system was first seriously investigated in European countries [1], and has become one of the popular design alternatives for space cooling in northwest Europe where the climate is relatively mild and dry.

In early 1990s, interest in the CRCP system began to increase once the condensation issues had been addressed by independent ventilation systems designed to meet the entire space latent load and the required ventilation rate. First of all, the energy conservation and indoor air quality (IAQ) benefits of the decoupled (or hybrid) system began to attract attention [2–4]. In addition, it was also indicated that the traditional negative perceptions on the CRCP system need no longer be valid [5].

In the recent time, integrated piping systems as surface cooling and heating systems in ceilings and walls has increased for room air conditioning. The positive effects of the cooling radiation exchange units in connection with the draft-free ventilation source an extremely comfortable and hygienic climate system for the people in the room. This system which is able to remove relatively high cooling loads and significantly saving energy, a variety of such systems has been developed for applications.

All known radiation heating- and cooling systems occupy the room enclosure surface with water pipes or ducts, i.e. this constructive integrated into the building or something more complicated with separate construction before hanging. As distinctive features of these systems are mainly the type of using materials, the distance constructive involvement cruder and channels as well as their free cross sections and flow direction.

Various types of hydronic radiant cooling systems include, metal ceiling panels, chilled beams, and tube imbedded in ceilings-floors are shown in Figure (1). Metal CRCPs are widely used and are frequently installed on T-bar grids designed to support the dropped acoustical ceiling. The panels in the dropped ceiling are top loaded with insulation to prevent heat gain from the plenum space. This top insulated CRCP system is also called a closed type CRCP system by the manufacture.

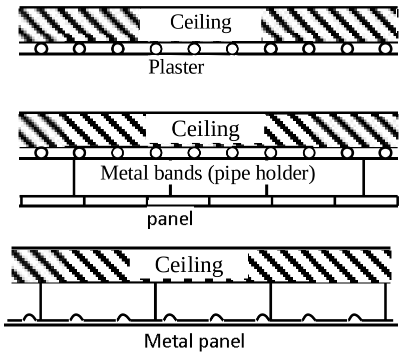

Figure (1): Construction and tubular configuration of a surface cooling system.

All these systems use water-carrying pipelines; there are special conditions in their calculation, which require an adjustment to the part of the accounting procedure. The performance of CRCP system is a function of many variables (as shown below).
In this research, we study the effect of the radiant surface material, the distance between the tubes and the thickness of the radiant plate on the efficiency and the temperature distribution on the radiant plate of the ceiling radiant system.

Literature review:

Researchers are studied theoretical and experimental radiant systems in different position and types with different energy resource, and there is ongoing research on how best to integrate and control radiant systems of different types, in different climates, and with different companion systems.
Wei-Hwa Chiang et.al [6] [2011], tested the effect of inlet water temperature and flow rate on cooling efficiency of a radiant ceiling system in Taiwan , The objective of this research is to figure out different supplying water temperature which accompanies flow rate embedded in radiant ceiling panels with a water circulatory system, they adopt five conditions of inlet water temperature 16, 18, 20, 22, and 24ºC with water flow rate at 40, 60, 80, and 100 LPM (liter per minute) to test the vertical temperature gradient inside the room and discuss the interactive effects between the parameters within one hour, The experimental values reveal that the better operative efficiency occurs as the inlet water temperature is 18 ºC and flow rate is 100 LPM without condensation of water on the radiant panel surface. The obtained results also that indicate as the inlet water temperature equals 24 and 22 ºC, the indoor air temperature only changes a little. This indicates that the difference is about 4-6 ºC between inlet water temperature and indoor air temperature.
Rama M. Vadaparti [7] [2010], used thermoplastic materials which are seldom used for floor. The primary focus of this work is to explore the suitability and adaptability of thermoplastics as an innovative energy saving floor-heating material. He found floor heating systems provide thermal comfort to humans and less energy use for providing the thermal comforts.
Néstor Fonseca Díaz [8] [2009], focuses on the experimental and theoretical analysis and modeling of the radiant ceiling systems as commissioning tool. A steady state model appears to be an appropriate tool for preliminary calculation, design and diagnosis in commissioning

processes. In order to validate this model the cooling ceiling system of a commercial building in Brussels is experimentally evaluated, the results show that the average difference between simulated and measured air and surfaces temperatures is lower than ±0.5 °C. The mean temperature of water and air room are of 13 -18 °C and 37- 49 °C for water and 24-26 °C and 21-23°C for air in cooling and heating mode respectively. And the water temperature drop across the ceiling is (2-3°C). And also, commissioning test results show that the influence of surfaces temperatures inside the room, especially the facade and ventilation are significant and that the radiant ceiling system must be evaluated together with its designed environment and not as separate HVAC equipment.

Scheatzle [9] [2006], explained many of the real-life problems encountered in implementing concrete-core and capillary tube radiant systems in real buildings. Concrete-core radiant floor cooling can lead to large stratification without sufficient air movement, such as through ceiling fans. Embedding pipe in concrete slabs can be problematic when systems fail, and access points are important especially at valves and joints where failures may occur.

Xuemin Sui and Guanghui Han [10][2006], tested three types of radiant ceiling (Concrete Radiant Ceiling with Embedded Pipes, Capillary Grid Radiant Ceiling and Metal Radiant Ceiling) are introduced, their air-conditioning effect, and operating control are comparatively analyzed. In addition, the application effect of a radiant cooling system employed in a residential building is analyzed and evaluated. All the analysis gives a reference for the application and promotion of radiant ceiling systems in China, and they concluded, the cooling load of building should be decreased so that the selected radiant cooling ceiling can be taken, based on the type of radiant ceiling.

Concrete radiant ceiling is main radiant terminal device in China; the auxiliary air system can make up for the cooling capacity shortage of this radiant terminal device. Rational design of radiant cooling system matching fresh air system and adjusting fresh air system can make up for the deficiency that concrete radiant ceiling is difficult to control in operating period.

Capillary radiant ceiling and metal radiant ceiling are sensitive to supply water temperature changes, and have smaller delay compared with concrete radiant ceiling, and can truly achieve separate control of room temperature. The main factors currently limiting the system are lack of real technical understanding, high price of capillary pipes and dew point control systems.

The body of research on radiant cooling/heating systems suggests that the strategy has great potential for reduced energy consumption which varies widely and depends on climate and radiant cooling type, favorable tie-in capabilities with low-temperature and low-intensity energy sources such as (solar system, cooling tower and ground heat pump), and also improved air quality and can control the humidity, reduced space requirements, and potentially even lower first costs.

Today, in Europe and increasingly in the United States radiant ceiling panel (RCP) cooling is finding new markets in tighter buildings, with controlled ventilation and dehumidification to prevent condensation problems.

Radiant surface thermal efficiency:

The performance of CRCP system is a function of the following variables:

- Tube diameter, D
- Flow rate per panel, m_w

- panel/tube length, b
- Tube center-to-center spacing, L
- Panel area, A
- fin thickness, h
- fin material, i.e., thermal conductivity, k
- Inlet cool water temperature, t_{wi}
- Room temperature, t_r
- Overall heat transfer coefficient, U
- piping arrangement, i.e., parallel tube or serpentine

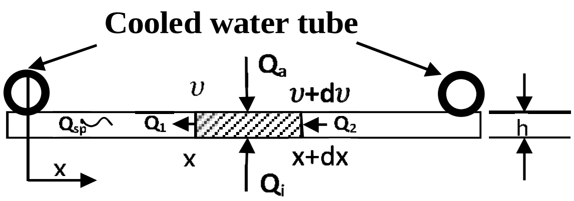

Figure (2): heat balance of a ceiling element.

Figure 2 shows a schematic drawing of the heat flow through a radiant plate between two cooled water flow pipes.
The question is, how to determine the temperature distribution on the radiant plate in the x-direction (perpendicular to the tubes, see Figure 2).
In this research, the temperature distribution in the conductive material (radiant area) between two pipes is obtained through mathematical analysis of the model shown in Figure (2). For quantification of the thermal resistance simplified consideration model is made and influence parameters are shown in Figure (2). It was assumed constant surface temperature of the tubes which carrying cooled water and the heat transfer is by radiation and convection from the material (radiant area). The temperature gradient in the flow direction is negligible. The calculation of the dynamic temperature of radiant area is made in the present work by the fin theory.
The thermal balance of the element layer, which one-dimensional heat conduction is assumed, leads to following equation:-

$\dot{Q}_1 + \dot{Q}_2 + \dot{Q}_i + \dot{Q}_a + \dot{Q}_{sp} = 0$ ....(1)

Where

$\dot{Q}_1$ =Heat out from the element $= k\, A_o \, \frac{\partial \vartheta}{\partial x}$

$\dot{Q}_2$ =Heat entering to the element= $-\, \mathrm{k}\, A_o \frac{\partial}{\partial x}\left(\vartheta + \frac{\partial \vartheta}{\partial x} dx\right)$

$\dot{\mathrm{Q}}_\mathrm{i}$ =Heat emitted from the room $= -\alpha_\mathrm{i}\, \mathrm{dA}\, \vartheta$

$\dot{\mathrm{Q}}_\mathrm{a}$ =Heat transfer from surrounding= $-\alpha_\mathrm{a}\, \mathrm{d\,A}\, \vartheta$

$\dot{Q}_{sp}$=Heat stored in the element=$dm\ c\frac{\partial\vartheta}{\partial\tau}$

$$-k\ A_o\frac{\partial\vartheta}{\partial x}dx-(\alpha_i+\alpha_a)dA\ \vartheta+\mathrm{k}\ A_o\frac{\partial}{\partial x}\left(\vartheta+\frac{\partial\vartheta}{\partial x}dx\right)+dm\ c\frac{\partial\vartheta}{\partial\tau}=0 \quad ....(2)$$

Where

Ao=h.b; Da=b.dx; dm=ρ.h.b.dx

And with good thermal insulation, i.e. lesser outside heat transfer the term $(\alpha_a\ dA\ \vartheta)$ is equal to zero. For the steady stat heat transfer, the heat stored in the element is equal to zero, i.e. the term $(dm\ c\frac{\partial\vartheta}{\partial\tau})=0$ .Then equation (2) can be written in the following form:

$$\frac{\partial^2\vartheta}{\partial x}-\frac{\alpha_i}{hk}\vartheta=0 \quad ....(3)$$

At x=0 $\vartheta=\vartheta_o$ and at x=L $\vartheta=\vartheta_o$

By using Finite difference methods, the solution of differential equation (3) is [11]:

$$\frac{\vartheta}{\vartheta_0}=\frac{e^{(x-L)\sqrt{\frac{\alpha}{hk}}}+e^{-x\sqrt{\frac{\alpha}{hk}}}}{1+e^{-L\sqrt{\frac{\alpha}{hk}}}} \quad ....(4)$$

Where

A_o=area of the element.
b= length of the element.
ϑ=temperature difference ceiling/room (t_x-t_r).
ϑ_o= maximum temperature difference ceiling/room at tube surface (t_p-t_r).
α_i= heat transfer coefficient by radiation and convection.
k= Thermal conductivity of the ceiling.
x= variable distance perpendicular to the two parallel tube.
L= the distance between center of tube.
h= thickness of the ceiling plate.

Equation (4) is the ratio of the temperature difference to available maximal possible temperature difference.

The thermal efficiency of the radiant surface is the ratio of the heat transfer to the maximum possible heat flow [11], i.e.:

$$\eta = \frac{2}{\sqrt{\frac{\alpha}{hk}}L} \frac{1-e^{-L\sqrt{\frac{\alpha}{hk}}}}{1+e^{-L\sqrt{\frac{\alpha}{hk}}}} \quad \text{..........(5)}$$

For the radiant surface without distance between tubes or a continuous water guide surface, the temperature difference (t_x-t_p) approximately equal to zero and the radiant surface thermal efficiency will be at its maximum value (η=1). So that the Radiant thermal efficiency describes the configuration of a surface system, in which a specific heat output with a minimum driving temperature difference is.
The average heat transfer coefficient for the interior surface can be assumed equal to (10W/m^2.K) as a reference value based on how this surface can be adopted under the usual conditions in climatic rooms including radiation component [12].

Results and discussion:

The research shows that the maximum difference between the temperature of the cooled surfaces (t_p) and room temperature (t_r) does not exceed (5 ^{o}C) and the room air temperature is 24-26 °C. To study the effect of the type of radiant material used in the ceilings on the radiant plate temperature, the ratio between the difference of the temperature distribution of the radiant plate and the cooled water pipes temperatures and room air temperature has been taken under consideration. Figures (3 to 5) shows the temperature distribution of the radiant plate between the water tubes in the plates of aluminum, iron and plastic materials. Figure (3) shows, that the proportion of the difference in temperature is equal to 80% when using sheets of aluminum thickness of 1 mm at a distance equal to 0.2 meters between the water tubes, while the ratio is equal to 50% when using iron sheets as shown in Figure (4). Figure (5) shows the temperature distribution on the plastic material radiant plate, the proportion of the difference in temperature is equal to 0.61 when using plastic tubes with plaster of thickness (1) mm at a distance equal to 15 mm.
To study the effect of the materials used in radiant surfaces, the thermal conductivity coefficient of the materials were varied as shown in Figure (6). The figure provide that, at constant value of distance between cooled water tubes, an increase in the thermal conductivity of the (5mm thick) radiant surface led to increase the efficiency of the radiant surface.
For all type of material used as radiant surface an increase in the distance between tubes arranged in the radiant surface led to decrease the efficiency of the radiant surface. Figure (6) indicate that the recoverable radiant surface efficiency depend strongly on the material of the surface and the distance between cooled tubes.
The relation between efficiency of the radiant plate material and the distance between water tubes for different thickness of plate are shown in figures (7, 8, 9). It was shown, that when the distance between the tubes is equal to 20cm and the thickness of the radiant plate is (1mm), the efficiency of the radiant surface is 90%, 60%, 18% for aluminum, iron and plaster material respectivley.

Conclusions:

The use of radiant cooling systems for room air conditioning is becoming very popular. In all type of radiant cooling systems the material, the thickness of radiant surface and geometry of contact between cooled water pipes and radiant surface have significant effect on the efficiency of system.

Aluminum material is the best material used as a radiant plate in radiant cooling system, although it's expensive. The subject of cost accounts is the most important factors that affect the use of these materials in radiant systems.

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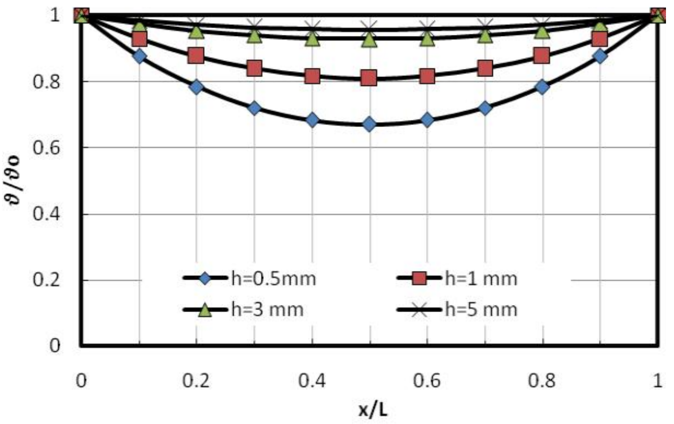

Figure (3): Temperature distribution between two pipes in radiant Alminium plate, K=220 W/m.k, L=0.2 m

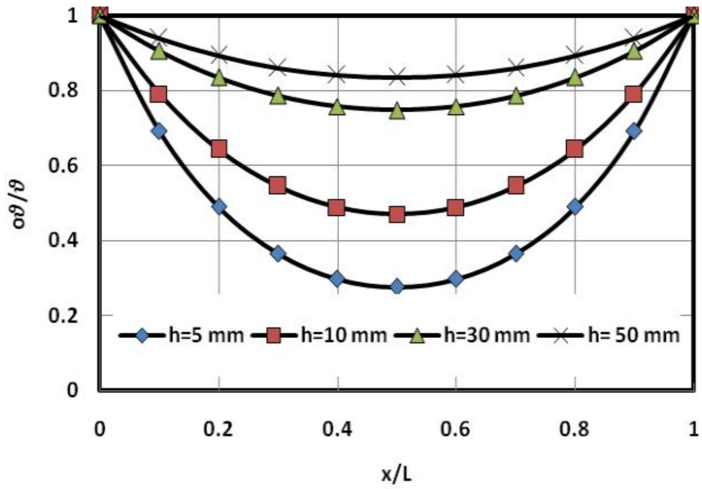

Figure (4): Temperature distribution between two pipes in radiant steel plate, K=52 W/m.k, L=0.2 m

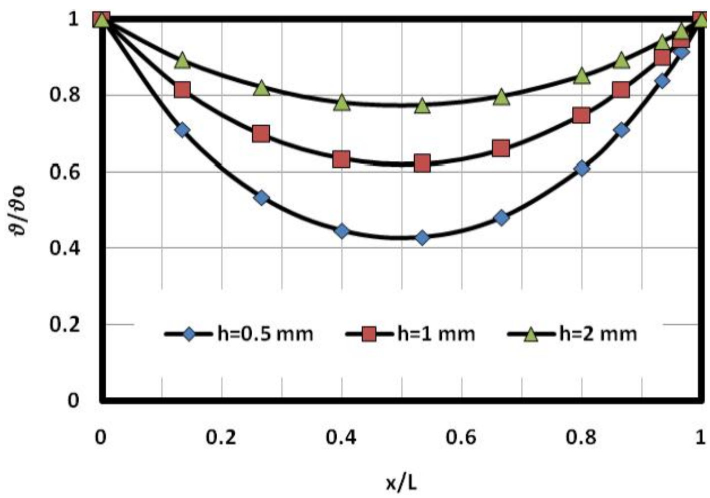

Figure (5): Temperature distribution between two plastic pipes with plaster, K=0.5 W/m.k, L=0.015 m

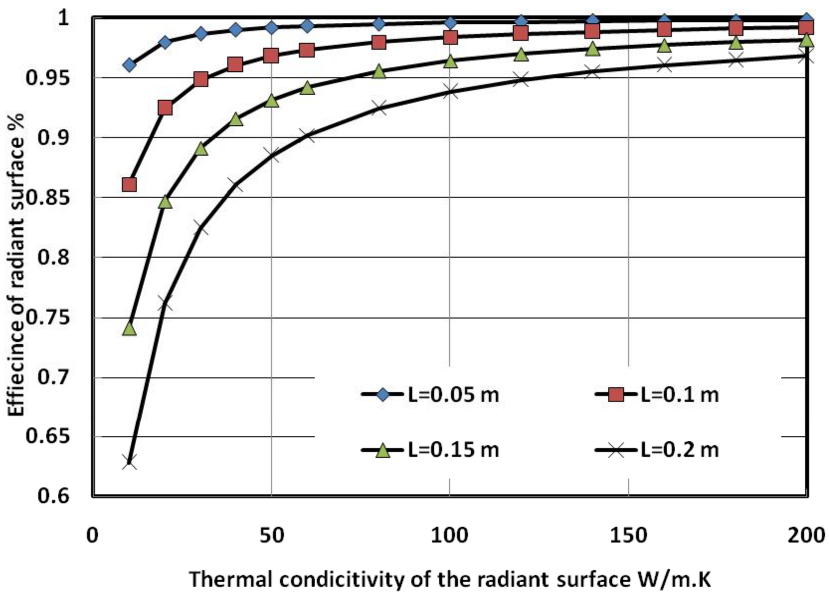

Figure (6): Effect of the radiant surface material and the distance between pipe on the radiant surface

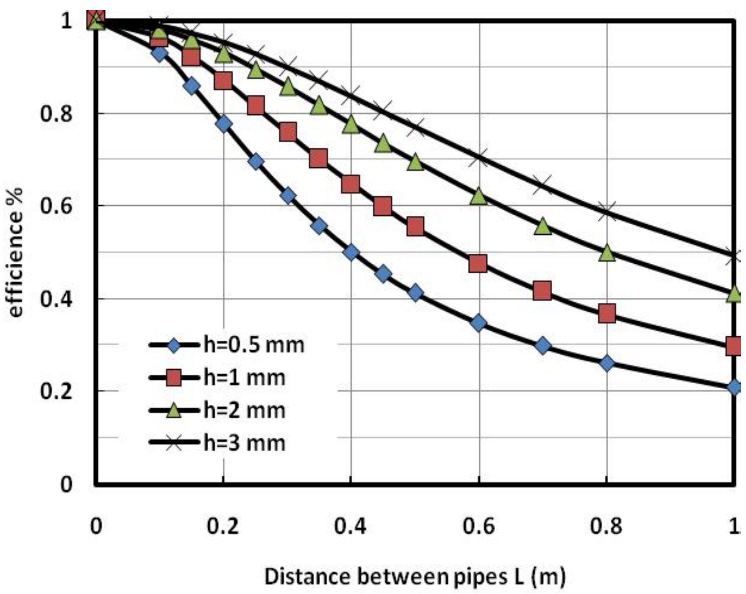

Figure (7): Effect of distance between pipes on the efficency of radiant plate, K=220 W/m.k

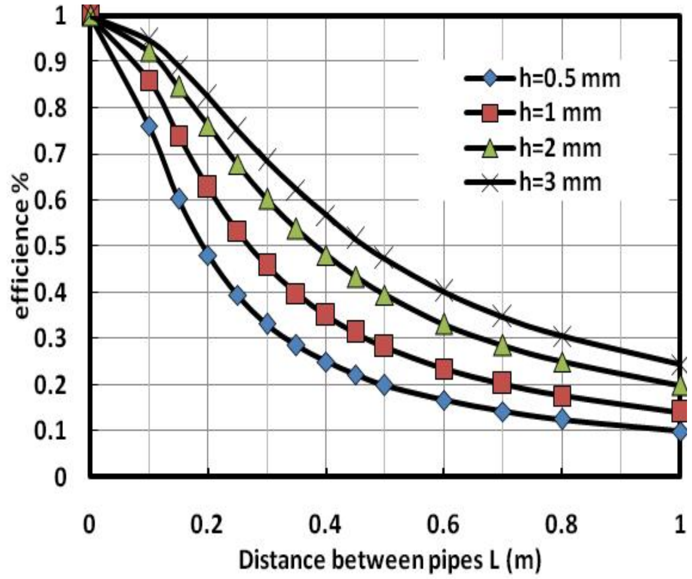

Figure (8): Effect of distance between pipes on the efficency of radiant plate, K=50 W/m.k

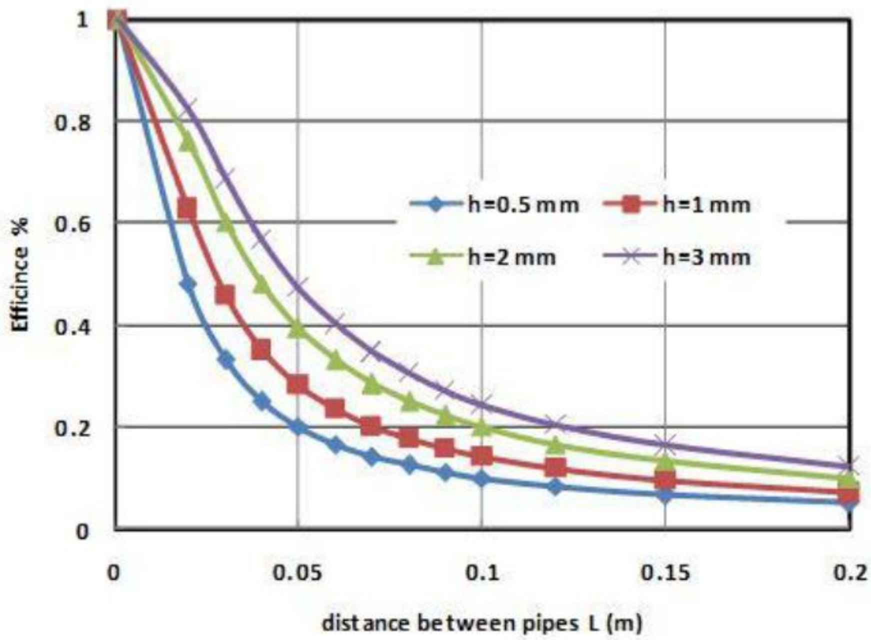

Figure (9): Effect of distance between plastic pipes on the efficiency of plastic radiant surface, K=0.5 W/m.k