The Effect of Magnetic Shiny Sheets on Radiator Output (*)

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Abstract:

The effect of altering the emissivity of the radiator surface facing the wall behind a radiator on the radiator heat output has been studied experimentally and numerically using computational fluid dynamics.

The results of a 3D RNG k-ε turbulent model agree well with the experimental results. The results indicate that the presence of a low emissivity surface decreases both the heat output from the radiator and the heat loss through the wall compared to a high emissivity surface. The radiator low emissivity surface decreases the heat transfer to the wall

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which causes the surface temperature of the wall to decrease, effectively reducing the heat transfer through the wall.

The results indicate that the energy saving from radiator can be increased by about (17.5%) through the use of a magnetic low emissivity radiator surface compared to a high emissivity one. This means that using a radiator surface with low emissivity facing the wall will increase the energy saving by decreasing the heat loss through the wall.

***Keywords**: Panel radiators, Heat transfer, surface emissivity, Radiation, Natural convection.*

Nomenclature:

A	Heat transferring surface area	(m^2)
Cp	Specific heat capacity	($Jkg^{-1}K^{-1}$)
g	Gravitational acceleration	(ms^{-2})
h	Heat transfer coefficient	($Wm^{-2}K^{-1}$)
K	Thermal conductivity of the fluid	($Wm^{-1}K^{-1}$)
L	Enclosure wall length	(m)
ℓ	Wall thickness	(m)
$\dot{m}$	Water mass flow rate	(kgs^{-1})
$\dot{Q}_c$	Convection heat transfer	(W)
$\dot{Q}_r$	Radiation heat transfer	(W)
$\dot{Q}_d$	Heat loss by Conduction through the wall	(W)
$\dot{Q}_t$	Total heat transfer from the radiator	(W)
$\dot{Q}_a$	Total heat transfer to the air	(W)
T_{in}	Water inlet temperature	(K)

T_{out}	Water outlet temperature	(K)
T_{w1}	Wall surface temperature facing radiator	(K)
T_{w2}	Wall surface temperature facing outside	(K)
U	Thermal conductivity of the wall	$(Wm^{-1}K^{-1})$
$\propto$	Thermal diffusivity	(m^2s^{-1})
ϑ	Kinematic Viscosity	(m^2s^{-1})
β	Thermal expansion coefficient	(K^{-1})
ΔT	Temperature difference	(K)

Dimensionless groups

Nu_L	Nusselt number $\left(\frac{hL}{K}\right)$	(-)
Ra_L	Rayleigh number $\left(\frac{g\beta\Delta TL^3}{\vartheta\alpha}\right)$	(-)

1.Introduction:

Radiators are the most popular central heating emitters in the UK. Of the various designs available, steel panel radiators, usually equipped with convection fins to improve their heat output, are common in domestic, business and industrial environments. In this type of device, hot water is passed through the hollow radiator. As the radiator is hotter than the air surrounding it, heat is transferred to the air and thus the water exits at a lower temperature [1].

The first law of thermodynamics states that in steady state heat flow, all of the energy put into a system must come out again as shown in figure(1). As radiators do no work, the heat transferred out must come from the hot water passing through them [2].

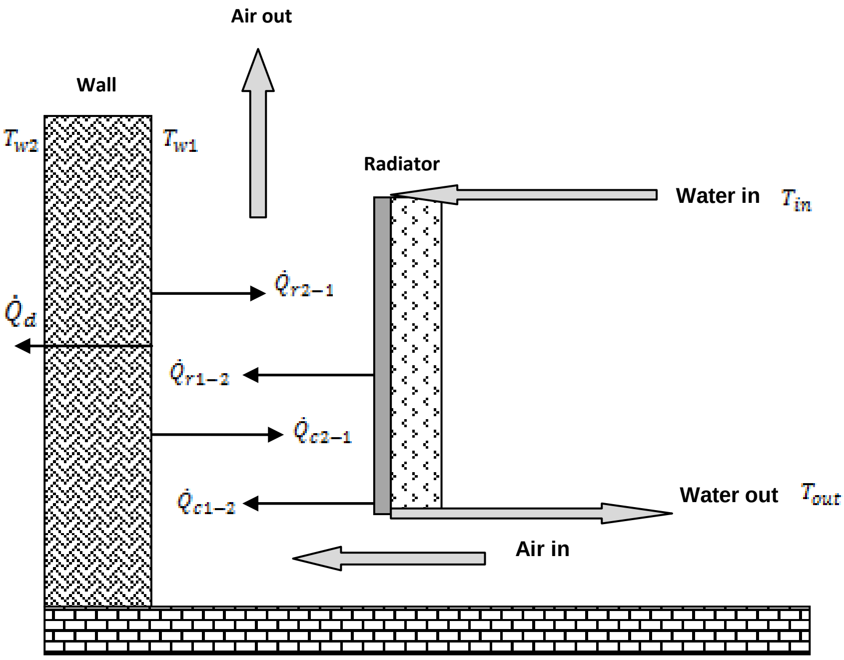

Figure 1. Heat balance for wall and radiator

Although called radiators, most of the heat output is by natural convection. The steady flow energy equation for the air flow around a radiator states that the rate of conductive heat transfer from the radiator is equal to the product of the flow rate of the air, the specific heat capacity of air and the change in temperature of the air across the radiator. The rest of the heat transfer is due to thermal radiation. This is based on the fourth power of the absolute temperature, and the emissivity of the surface, which is the ratio of energy radiated from a material's surface to that radiated from a black body (which has an emissivity of 1) at the same temperature and wavelength and under the same viewing conditions [3].

For example a 0.69m by 1.556m single radiator has a heat output of 1637W and a surface area of 1m^2 per side [4]. The radiation heat transfer into the room from the panel facing it is just over 400W for 75°C radiator and 20°C room temperatures. Therefore ¼ of the heat transfer is due to radiation. If account is taken of the side facing the wall [1], the proportion of heat transfer due to radiation rises to more than (50%) .

The heat output from a radiator depends on the emissivity of the wall facing it, the wall surface roughness and aspect ratio (the ratio between the air gap between the radiator and the wall to the radiator height). In previous publications [1-3] it was reported that, the presence of a high emissivity surface and a high roughness surface at the wall increases the mass flow rate and air velocity behind the heat source compared to a reflective material. The heat transfer rate was increased by more than (26%) through the use of a black saw-tooth instead of a reflective smooth wall [1]. The spacing between the wall and radiator affects both the view factors for the heat transfer by radiation and the boundary layer for the heat transfer by convection. For a large aspect ratio, an independent boundary layer develops at each surface and a condition similar to that of natural convection flow over a vertical plate takes place. However, for a small aspect ratio, the boundary layers developed on both plates merging to a fully developed flow condition. The velocity gradient at the wall increases and the thickness of the wall thermal layer decreases with the increase of the aspect ratio resulting in an increase in the heat transfer coefficient [5].

A correlation has been obtained for the thermal optimum aspect ratio that maximizes the Nusselt number, Nu_L, for vertical walls in channels, where the higher value of Rayleigh number, Ra_L, the lower value of optimum aspect ratio [6, 7]. A well-known method to increase the heat transfer from a surface is to roughen the surface either randomly with sand grains or by use of regular geometric roughness elements on the surface, where the increase in heat transfer is accompanied by an increase in the resistance to fluid flow [7].

The thermal performance of radiators is measured in accordance with EN 442 part 2 [8], which specifies a standard test room, subject to certain test conditions.

There are several facts that can affect the radiator output. The output of the radiators can be slightly increased by decreasing their height above the ground and by increasing their spacing from the wall [9]. Facing the wall adjacent to the radiator with an insulated reflector can lower the heat loss through the wall by (70%) [10]. This will also lower the heat output from the radiator [1, 2], however as the heat will reflecting back to the radiator. The heat transfer from radiator can be increased by (20%) through the use of a black wall facing it instead of a reflective wall [2]. Placing two high emissivity sheets between the radiator panels can produce between (71%) and (88%) of the heat output of a finned double radiator [3]. Increasing the emissivity and the surface roughness will increase the heat output from the radiator by (26%) instead of using a smooth shiny surface [1].

These facts show how important the use of surface emissivity to decrease the heat loss through the wall or increase the heat output from radiator. It was decided to investigate whether it was possible to increase the total heat saving from the radiator by using a magnetic shiny sheet fixed on the radiator surface facing the wall. The work was done on a commercial available magnetic shiny sheet [11].

Experimental work:

A simplified domestic hot water central heating system was constructed for this work. A diagram of this is shown in figure (2). The heat input device was a 3kW immersion heater. To keep the temperature steady (to within ±0.1°C) in accordance with the European standard EN 442-2 [8], a PID temperature controller was fitted to the heater to match the energy input to the heater with the output from the system. The PID controller provides proportional, integral and derivative control, and has been adjusted to automatically compensate for temperature changes in the system. The flow rate was measured using a rotameter. The water was circulated by a standard central heating pump and controlled through the use of a bypass and valves.

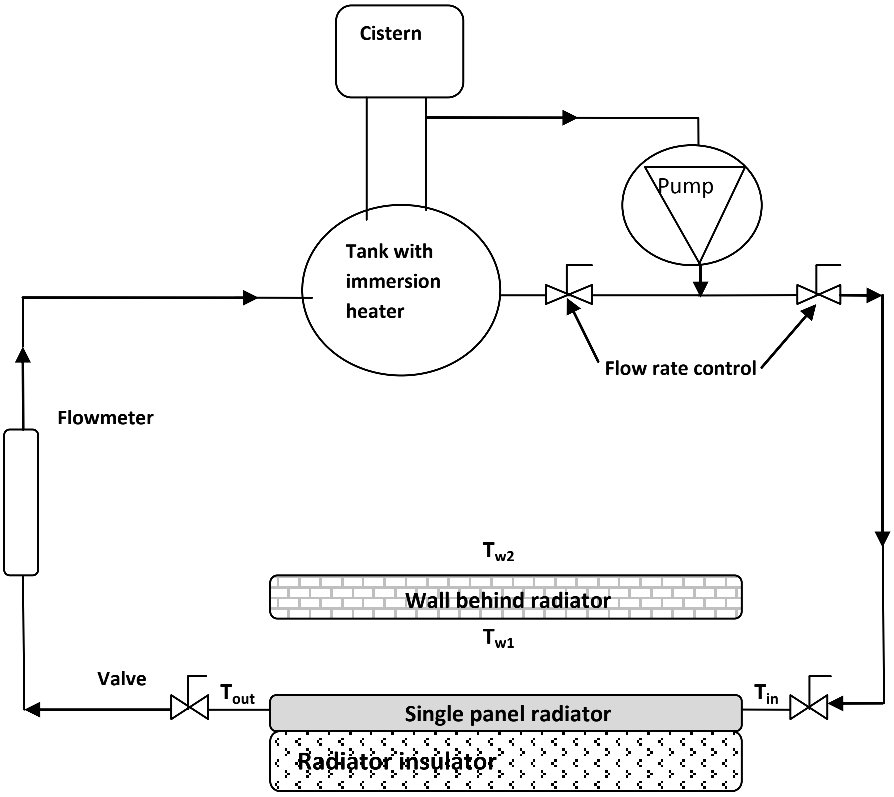

Figure 2. Diagram of the used apparatus

After the pump, a standard 600mm high by 600mm wide single plate radiator was arranged and supported 150mm above the floor using steel work. The water temperature before and after the radiator was measured with T-type thermocouples attached to the surface of the pipes, which were insulated with 10mm thick foam. The pipes were assumed to be at the same temperature as the water. The thermocouples were attached to a PC based data acquisition system to monitor and record the temperatures at every 15 second. The average temperature of the inlet and outlet of the radiator were recorded as T_{in} and T_{out}. The radiator was insulated to a thickness of 50mm on the side that faced away from the wall using expanding foam insulation with a thermal conductivity of 0.04w/m.K.

The wall was constructed from 20mm thick high density Particle board of thermal conductivity (U=0.17 W/m.K). Three thermocouples were placed into each side of the wall. The average temperature of each of the three thermocouples were calculated and recorded as T_{w1} and T_{w2}. The wall was positioned 50mm from the radiator, to ensure that the aspect ratio of the gap was 1 to 12. The water flow rate was adjusted to get sufficient temperature difference (10 °C) as specified by the European standard.

Tests were carried out to measure and compare the heat transfer to the air with the different surfaces. The air temperature and velocity profiles at the middle of the top of the radiator were measured using a thermistor type anemometer. All the temperature readings and the velocity readings taken using the thermocouples or the anemometer had an error of ±0.3°C and ±0.015m/s respectively.

The heat lost by the radiator must be conducted through the wall, reflected back into the radiator or convected into the air as shown in figure (1). A small amount will also be radiated into the room, but this is ignored for the analysis. Thus it is possible to measure the heat output of the radiator to the air using the energy balance for the two surfaces shown in figure (1) and calculated by the authors [1]:

From the energy balance on the wall surface facing the radiator it can be stated that:

$$\dot{Q}_a = \dot{Q}_t - \dot{Q}_d \qquad (1)$$

Where

$$\dot{Q}_t = m \cdot Cp(T_{in} - T_{out}) \quad (2)$$

And

$$\dot{Q}_d = \frac{UA}{\ell}(T_{w1} - T_{w2}) \quad (3)$$

The accuracy of the results can be estimated by summing all of the instrumentation errors and are approximately ±6% for $\dot{Q}_a$, ±5% for $\dot{Q}_t$ and ±5% for $\dot{Q}_d$. The principle source of error is due to the uncertainty in the thermocouple and flow rate readings.

CFD modelling:

A CFD simulation was carried out to see the effect of using a magnetic shiny sheet fixed on a surface radiator facing the wall, using the commercially available Gambit and Fluent packages (version 6.3.26) [12].

A 3-D model of a 4×3×3m room size (as specified by the European standard EN442-2) was created using a non-uniform grid. Only half the room was modelled and a symmetry boundary wall used. The non-uniform grid was created in order to concentrate the main calculation on the areas of interest. This higher density grid is around the radiator and also around the wall surfaces. A convergence study was undertaken, which showed the mesh was sufficient for a grid independent solution.

In this model, the heat source was set to 75°C (European standard). The room walls were set as wood of thermal conductivity 0.173 W/m-k. The surrounding outside air was set to constant temperature 20°C. The insulation of the back surface of the radiator was set as insulator with thermal conductivity 0.04 W/m-k. The emissivity of all the walls were set to 0.9 except the surface facing the radiator was altered either to 0.05 (reflector) or 0.96 (black).

The RNG k- ε turbulent model was used for all the four models. The near wall model used was the enhanced wall treatment with thermal and buoyancy effects. The Discrete Transfer Radiation Model (DTRM) was implemented.

Experimental Results:

The total heat transferred from the single panel radiator, the heat loss through the wall was extracted, and, using equations 1, 2 and 3, the calculated heat transfer to the air for each different surface was calculated. These are shown in table (1) for air gap of 50mm.

It can be seen that, compared to a radiator without a magnetic shiny sheet, the total heat output from the radiator was decreased by more than (25%) through the use of a magnetic shiny sheet on radiator surface. The heat transfer to the air was decreased by more than (17%) through the use of a magnetic shiny sheet on radiator surface compared to a surface radiator without magnetic shiny sheet.

The heat loss through the wall can be reduced to a certain value by using an insulator to minimise the heat loss through the wall and maximise the heat transfer to the air. Also the heat loss through the wall can be reduced to more than (50%) by using a low emissivity wall surface as described by the authors [1, 2]. From table (1) the heat loss through the wall was reduced to more than (95%) through the use of a magnetic shiny sheet on radiator surface compared to a surface radiator without magnetic shiny sheet.

Table 1 Comparison of experimental heat transfer rates used with and without magnetic sheets

Radiator surface	$\dot{Q}_t$ (W)	$\dot{Q}_{loss}$ (W)	$\dot{Q}_a$ (W)
Without magnetic sheets	114.8	21.1	93.7
With magnetic sheets	84.8	0.9	83.9

Figure (3) shows the temperature results measured at the top of the radiator in the 50mm air gap for the two cases, with and without the magnetic shiny sheet on radiator surface. It can be seen that the temperature very close to the radiator is reduced to about 59°C for a surface radiator with a magnetic shiny sheet compared to 70°C for a surface radiator without this. On the wall side, the temperature decreases from 45°C without a magnetic shiny sheet to 29°C with a magnetic shiny sheet. At the middle of the air gap far from the wall the temperature difference between both cases was between 1°C and 4°C.

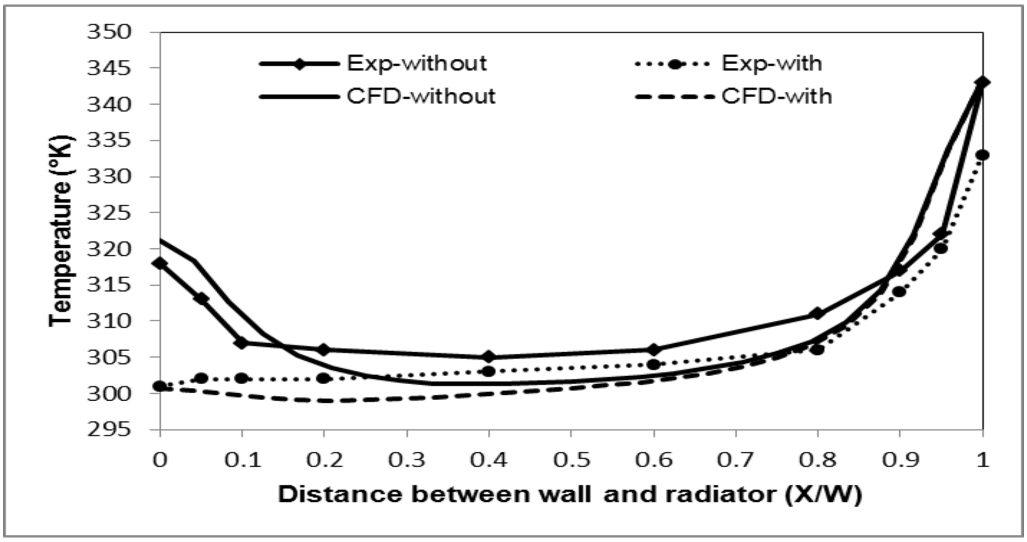

Figure 3. Temperature profiles at top of radiator with and without magnetic shiny sheets

The velocity profiles at the top of the radiator in the air gap are shown in figure (4). It can be seen that near the radiator, the air velocity for the case of a radiator without a magnetic shiny sheet is greater than that of surface radiator with one by about between (8%) and (25%) . Near the wall, the air velocity for the surface radiator without a magnetic shiny sheet is (40%) greater than that of surface radiator with magnetic shiny sheet. At the middle of the air gap the measured velocity for the two cases was between (6%) and (30%) .

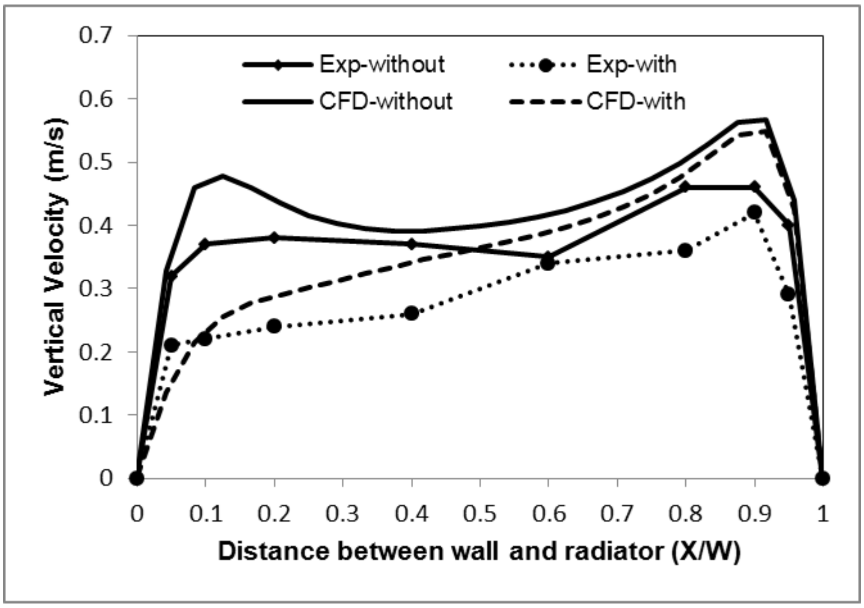

Figure 4. Velocity profiles at top of radiator with and without magnetic shiny sheets.

CFD Results:

From the model of a single panel radiator with an air gap of 50mm, the total heat transfer, the heat transfer by radiation and the calculated heat transfer by convection are shown in table (2). It can be seen that, compared to a surface radiator without magnetic shiny sheet, the total heat output from the radiator was decreased by about (40%) through the use of a magnetic shiny sheet on radiator surface. The heat transfer by convection from the two cases was almost the same. The heat transfer by radiation is reduced to more than three-quarters through the use of a surface radiator with a magnetic shiny sheet compared to a surface radiator without magnetic shiny sheet.

Figure (3) shows the temperature results at the top of the radiator for the CFD model compared with the experimental result. It can be seen that the temperature profiles have the same trend, for CFD and experimental results. On the radiator side the difference between the CFD and the experimental results with and without magnetic shiny sheet is less than 10°C and 4°C for the two cases. On the wall side the difference between the CFD and experimental results with and without magnetic shiny sheet is less than 3°C and 4°C for the two cases. At the middle of the air gap the temperature difference between all cases is less than 4°C.

Table 2 Comparison of CFD heat transfer rates for the system used with and without using magnetic sheets

Radiator surface	$\dot{Q}_t$ (W)	$\dot{Q}_{loss}$ (W)	$\dot{Q}_r$ (W)	$\dot{Q}_c$ (W)
Without magnetic sheets	99.5	14.8	51.0	48.4
With magnetic sheets	60.2	1.8	12.2	48.0

The velocity profiles at the top of the radiator from the CFD and experimental results are shown in figure (4). From the figure it can be seen that near to the radiator there is less than (8%) difference between the CFD and experimental results for a surface radiator without magnetic shiny sheet and less than (23%) for a surface radiator with a magnetic shiny sheet. At the wall side the difference between the CFD and experimental results for a surface radiator without a magnetic shiny sheet is less than (11%) and less than (17%) for a surface radiator with magnetic shiny sheet. In the middle of the air gap, the difference between the CFD and experimental results for a surface radiator without magnetic shiny sheet is less than (14%) and less than (23%) for a surface radiator with magnetic shiny sheet.

Discussion and conclusions:

The results indicate that using magnetic shiny sheets on the radiator surface facing the wall will decrease the heat loss dramatically resulting in increase of the energy saving.

The results in table (1) and figures (3) and (4) show that decreasing the surface emissivity of the radiator will decrease the heat output from the radiator by more than (25%) . This is due to the temperature of the wall surface decreasing causing the air velocity and hence the mass flow rate to decrease, which in turn decreases the heat transfer to the air by more than (17%) .

As shown in tables 1 and 2 and figures (3), and (4), the CFD results are seen to agree well with the experimental results. On the radiator and wall sides, the difference between the CFD velocity profile and the experimental one is small (less than (9%)) in the case of surface radiator without magnetic sheets and this difference increases to double for the case of surface radiator with magnetic sheets.

The temperature profiles for the CFD results on the radiator side also agree well with the experimental results for the two cases with and without magnetic shiny sheets and the difference between them are small. This difference between CFD and experimental results for the two cases becomes less than 4°C at the middle between the radiator and the wall and on the wall side.

The results show that decreasing the surface emissivity will decrease the heat loss through the wall by more than (95%) (this is because the radiation heat transfer from the radiator to the wall decreases by more than three quarters), which results in increase in the total energy saving from the radiator by about (17.5%) compared to a surface radiator with high emissivity. So using a magnetic shiny sheet on the radiator surface is recommended to be used specially for uninsulated walls.

In conclusion, this work shows that using a magnetic shiny sheet on the radiator surface facing the wall will greatly decrease the heat loss through the wall which will clearly save energy.

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