The effect of radiator size and thermal properties on radiator output

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Abstract **– The effects of altering the emissivity and the roughness of the wall behind the radiator on the radiator heat output have previously been numerically and theoretically studied by the author. This work extends these results by studying the effect of radiator size on the thermal properties and radiator output.**

In this research a numerical study was performed using the RNG k-ε turbulent model for a hot wall temperatures 55C°, 65 C° and 75C° and for radiator size aspect ratios 2.0, 1.5, 1.0 and 0.5 and with three aspect ratios 2.0, 1.0 and 0.5 and for two emissivities 0.95(black) and 0.05(reflector). This allows the calculation of total heat transfer from the radiator, the radiation heat transfer and the heat losses through the cold wall and the velocity profiles between the hot and cold walls at different y/H levels. The numerical calculations were performed using the ANSYS 17.2 workbench software.

The results indicate that the total heat transfer increases linearly as the size aspect ratio increases and as the aspect ratio decrease. Also the highest reduction in heat losses through the wall occurs at the highest size aspect ratio and for all cases it is happened at aspect ratio equal to 1/12.

Index Terms **—Panel radiator, Natural convection, Surface emissivity, Radiation, Aspect ratio.**

Nomenclature

H	Radiator height (m)
Q_c	Convection heat transfer (W)
Q_r	Radiation heat transfer (W)
Q_{tot}	Total heat transfer from radiator(W)
S	Distance between wall and radiator (m)
W	Radiator width (m)
Dimensionless groups	
AR	Radiator to wall aspect ratio (S/H)
SAR	Radiator height to width size aspect ratio (H/W)

I. Introduction

Radiators are the most popular central heating emitters in the UK. Of the various designs available, steel panel radiators 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 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, 2] it was reported that, the presence of a high emissivity 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 20% through the use of a black instead of a reflective wall. A correlation has been obtained for the thermal optimum aspect ratio that maximizes the Nusslet number, Nu_L, for vertical walls in channels, where the higher value of Rayleigh number, Ra_L, the lower value of optimum aspect ratio [3, 4].

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 [5]. The large-scale circulation interacts with the surface roughness and produces more thermal plumes from the tip of the rough element causing the heat transfer across the rough surface to increase [6].

Facing the wall adjacent to the radiator with an insulated reflector can lower the heat loss through the wall by 70% [7]. This will also lower the heat output from the radiator [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]. The total heat transfer from the radiator can be increased by about 26% through the use of a high emissivity saw-tooth surface compared to a smooth shiny one [8]. This means that using a wall surface with high roughness and emissivity behind the radiator will certainly increase the heat output from the radiator.

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 is. Also it shows how important increasing both the surface area and surface roughness on the heat output from radiators can be. It was decided to investigate the effect of the radiator size with the other thermal properties on the total heat transfer from the radiator by changing the radiator height and keeping the depth constant. The work was done on a range of a hot wall temperatures ranging from 50C° to 75C° and for radiator size aspect ratios 2.0, 1.5, 1.0 and 0.5 and with three aspect ratios 2.0, 1.0 and 0.5 and for two emissivities 0.95(black) and 0.05(reflector).

II. CFD MODELLING

To fully understand the effect of radiator size aspect ratio on radiator output and the air flow around and between the radiator and the wall surfaces, CFD simulations were carried out, using a free ANSYS version 17.2.

Twelve 2-D models of a 4×3m room size as specified by the European standard EN442-2 [9] were created as shown in figure 1, for four size aspect ratios 2.0, 1.5, 1.0 and 0.5 and three aspect ratios 2.0, 1.0 and 0.5 using a non-uniform grid. The non-uniform grid was created in order to concentrate the main calculation on the areas of interest. The higher density grid is around the radiator and also around the wall surfaces. A convergence study was undertaken, which showed the mesh is sufficient for a grid independent solution.

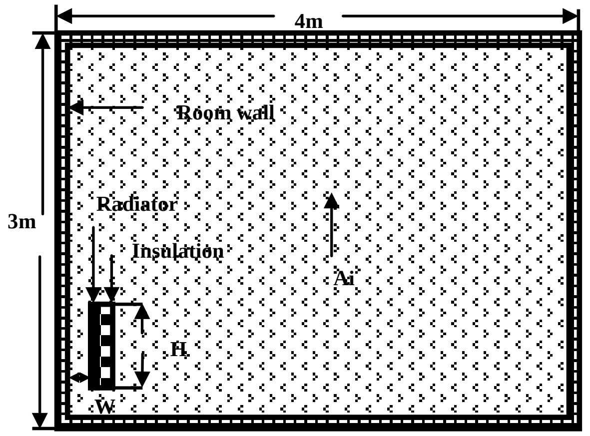


Figure 1 Schematic diagram of the radiator with the insulation inside the room

In this model, the heat source was set to 75°C (European standard) and for other two temperatures 65°C and 55°C for a comparison. 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 0.95 (black).

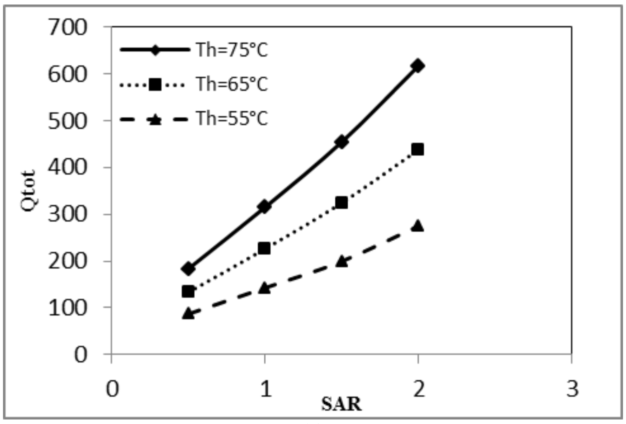
Researchers in [10] have compared four turbulence models for the turbulent natural convection in enclosures they have found that the RNG k-ϵ model agreed better with the experimental results than the other models. Others in [11] have compared eight turbulence models for predicting airflow and turbulence in enclosed environments they have found that between the RANS models, the RNG k-ϵ model produced the best results. Also researchers in [12]studied and analysed the influence and performance of five numerical models on the simulation of free and forced convection in double-glazed ventilated facades, they found that the RNG k-ϵ model performed better for predicting heat transfer than the other turbulence models, compared with experimental results. For these the RNG k- ε turbulent model was used in this study. The near wall model used was the enhanced wall treatment with thermal and buoyancy effects. The discrete transfer radiation model was implemented. By controlling the under-relaxation, all the twenty four models were converged with all residuals below 6×10^{-5}.

III.CFD RESULTS

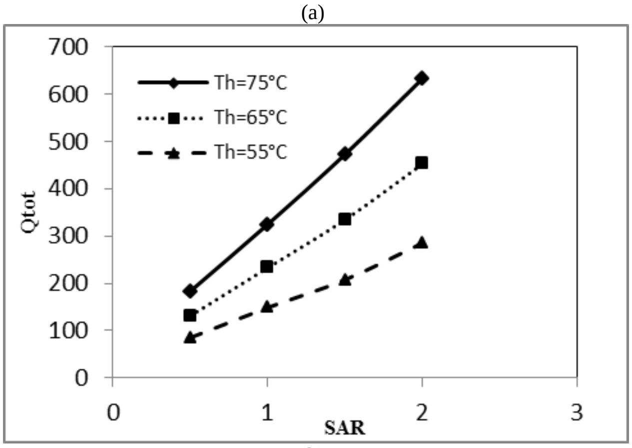
The total heat transferred from the single panel radiator for different radiator size aspect ratios (SAR) 0.5, 1.0, 1.5 and 2.0 are shown in figure 2. The figure shows the total heat transfer as a function of radiator size aspect ratios and for three radiator wall temperatures 55°C, 65°C and 75°C. Where figure 2a is for the aspect ratio 1/8, figure 2b is for aspect ratio 1/12 and figure 2c is for aspect ratio 1/24. From the figure it can be seen that as the radiator wall temperature increases the total heat transfer increase as well for the three aspect ratios. Also from the figure the total heat transfer increases from 52% to 62% as the radiator wall temperature increase from 55 to 75 for all aspect ratios. Moreover the total heat transfer from the radiator increases linearly as the size aspect ratio increase.

The ratio of convection to radiation heat transfer as a function of radiator size aspect ratios is shown in figure 3. From the figure it can be seen that the ratio of convection to radiation heat transfer is decreases as the radiator wall temperature increase for all aspect ratios 1/8, 1/12 and 1/24. Also from figure 3a aspect ratio 1/8 it can be seen that as the size aspect ratio increases the convection to radiation ratio increase as well where it increases linearly from size aspect ratio 0.5 to 1.0 then it is increases slightly for the other size aspect ratios. Moreover from figure 3b aspect ratio 1/12 the convection to radiation ratio is almost constant for all size aspect ratios and all radiator wall temperatures. Furthermore from figure 3c aspect ratio 1/24 the convection to radiation ratio is decreases linearly from size aspect ratio 0.5 to 1.0 then it is decreases slightly for the other size aspect ratios.

The heat loss through the wall was calculated and compared for the wall facing the radiator and when the emissivity of the wall altering between black (ε=0.95) and shiny (ε=0.05). The comparison was found that; the reduction of heat loss through the wall was minimum (70%) at lower size aspect ratio (SAR=0.5) and higher aspect ratio (AR=1/8) and lower radiator wall temperature (Th=55°C). Conversely, the reduction of heat loss through the wall was maximum (84%) at higher size aspect ratio (SAR=2.0) and medium aspect ratio (AR=1/12) and higher radiator wall temperature (Th=75°C). For all the calculated cases the highest reduction in heat loss through the wall happened at medium aspect ratio (AR=1/12).



(a)



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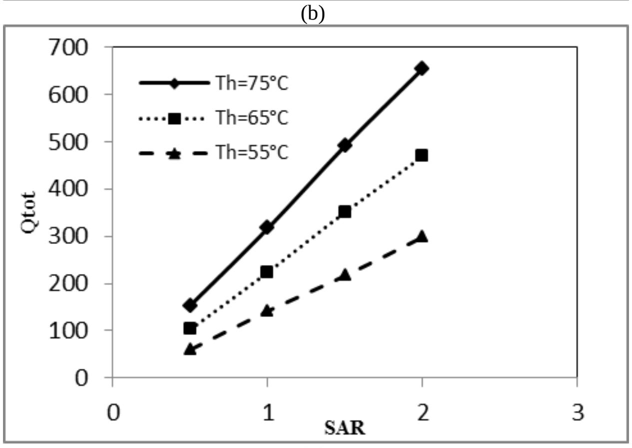
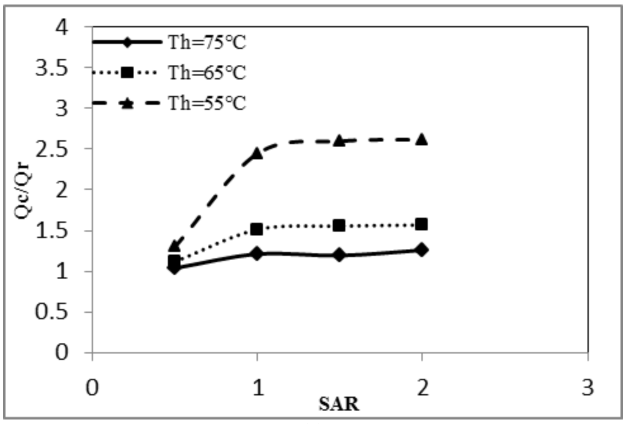
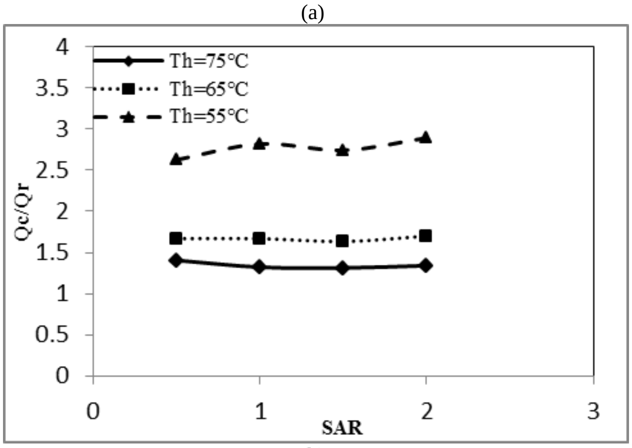


(C)

Figure 2 Relation between the size aspect ratio and the total heat transfer for AR a) 1/8 b) 1/12 c) 1/24.



(a)



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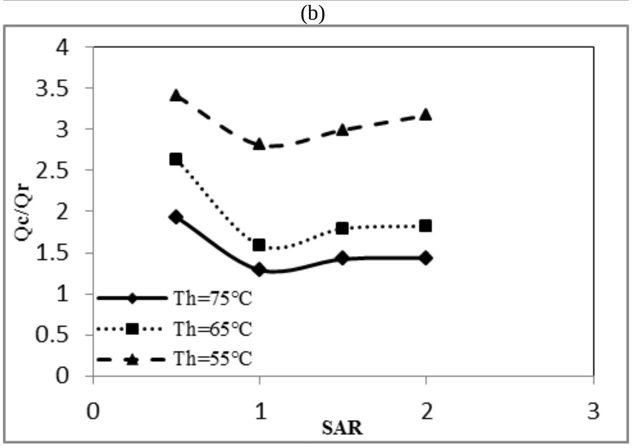
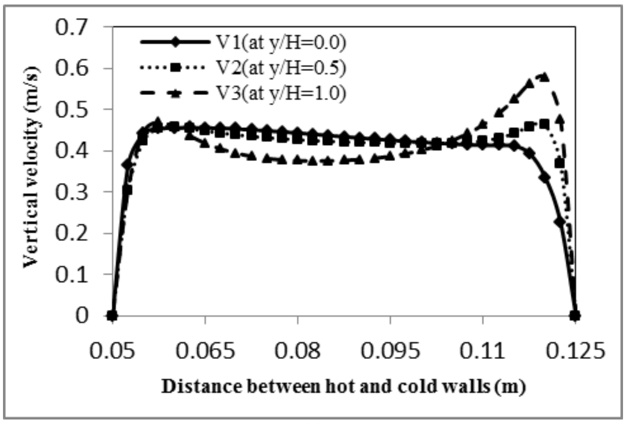


(C)

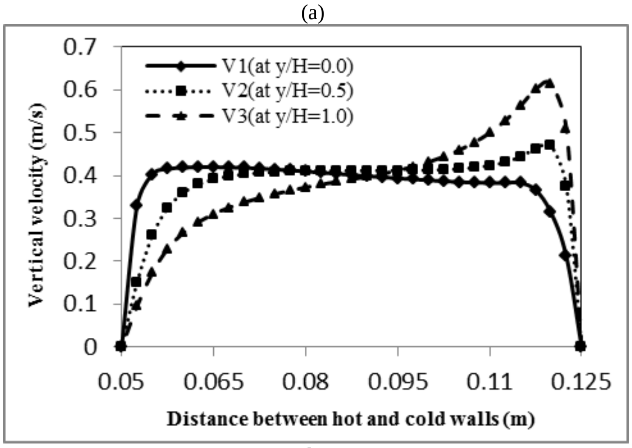
Figure 3 Relation between the size aspect ratio with the (Qc/Qr) for AR a) 1/8 b) 1/12 c) 1/24.

The velocity profiles between the hot and cold walls were provided for different size aspect ratios and different wall temperatures and different height ratios y/H between the hot and cold walls. The velocity profiles between the hot and cold walls were shown in figures 4, 5, 6 and 7. The velocity profiles between hot and cold walls and for size aspect ratio (SAR=1.5) are shown in figure 4. From figure 4a, for black wall (ε=0.95), it can be seen that at the bottom (y/H=0.0) where the air enters the gap, the flow is concentrated towards the wall.

At the radiator and the wall sides the flow ascends and the boundary layer continues to develop until the top of the radiator (y/H=1.0). Conversely, from figure 4b and for the shiny wall (ε=0.05) the boundary layer develops on the wall side at the bottom (y/H=0.0) of the radiator then starts to decrease until the top of the radiator (y/H=1.0); almost all of the boundary layer development takes place on the radiator side. Also from figure 5 it can be seen that the velocity magnitude at the top of the radiator for shiny wall (ε=0.05) is higher than the velocity magnitude for black surface (ε=0.95) on the radiator hot wall side.



(a)



(b)

Figure 4 Velocity profiles between hot and cold walls for ARS= 1.5 and at y/H=0.0, 0.5 and 1.0 and for a) ε=0.95 b) ε=0.05.

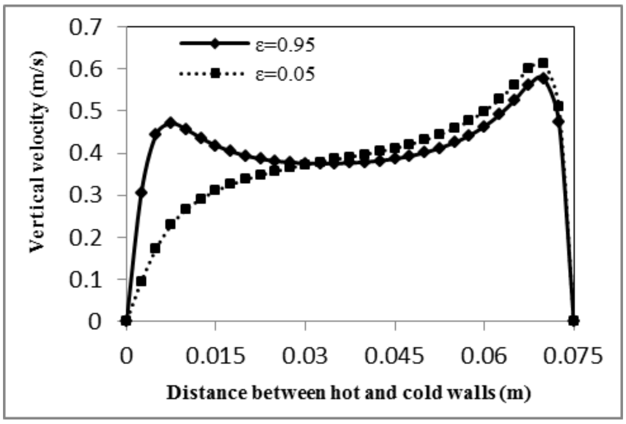


Figure 5 Velocity profiles between hot and cold walls for ARS= 1.5 and at y/H=1.0 and Th=75°C.

At the same time, the velocity magnitude for the black wall (ε=0.95) is greatly higher than the shiny surface (ε=0.05) on the cold wall side. Moreover from figure 6 it can be seen that the velocity magnitude at the top of the radiator is increases, through-all the gap between hot and cold walls, as the radiator hot wall temperature increase. Furthermore from figure 7 it can be seen that the velocity boundary layer and the velocity magnitude is increases as the radiator size aspect ratio increase.

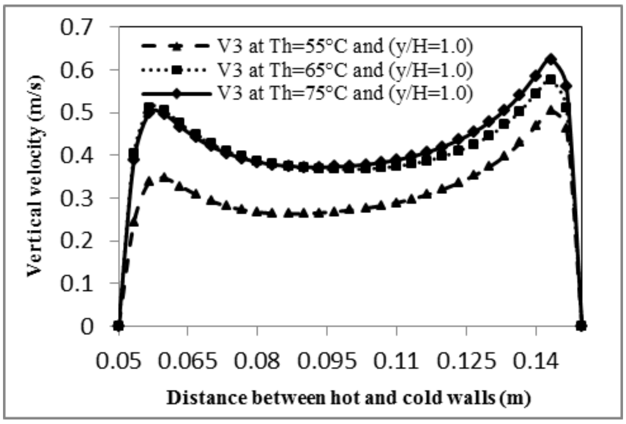


Figure 6 Velocity profiles between hot and cold walls for ARS= 2.0 and at y/H=1.0 and Th=55°C., 65°C and 75°C.

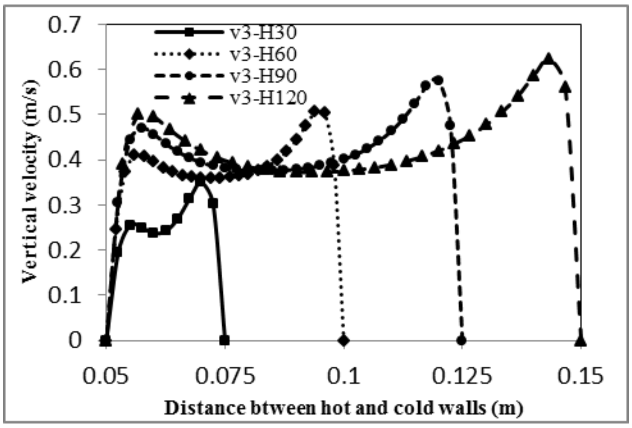


Figure 7 Velocity profiles between hot and cold walls for AR=1/12 and at y/H=1.0 and Th=75°C and ARS=0.5, 1.0, 1.5 and 2.0.

IV. DISCUSSION AND CONCLUSIONS

The results indicate that the total heat transfer increases linearly as the radiator size aspect ratio increases and as the aspect ratio decrease. Also the highest reduction in heat losses through the wall occurs at the highest size aspect ratio. Furthermore the vertical velocity between the hot and cold walls increases as the size aspect ratio increase.

The total heat transfer increases as the radiator wall temperature increase for the three aspect ratios. Also the total heat transfer increases from 52% to 62% as the radiator wall temperature increases from 55 to 75 for all aspect ratios. Moreover the total heat transfer from the radiator increases linearly as the size aspect ratio increases.

The ratio of convection to radiation heat transfer is decreases as the radiator wall temperature increase for all aspect ratios 1/8, 1/12 and 1/24. For aspect ratio 1/8 the convection to radiation ratio increase as the size aspect ratio increases where it increases linearly from size aspect ratio 0.5 to 1.0 then it is increases slightly for the other size aspect ratios. Moreover for aspect ratio 1/12 the convection to radiation ratio is almost constant for all size aspect ratios and all radiator wall temperatures. Furthermore, for aspect ratio 1/24 the convection to radiation ratio is decreases linearly from size aspect ratio 0.5 to 1.0 then it is decreases slightly for the other size aspect ratios.

The reduction of heat loss through the wall using a shiny surface (ε=0.05) was minimum (70%) at lower size aspect ratio (SAR=0.5) and lower radiator wall temperature (Th=55°C). Conversely, the reduction of heat loss through the wall was maximum (84%) at higher size aspect ratio (SAR=2.0) and higher radiator wall temperature (Th=75°C). For all the calculated cases the highest reduction in heat loss through the wall happened at aspect ratio (AR=1/12).

At the radiator and the wall sides the flow ascends and the boundary layer continues to develop until the top of the radiator for black surfaces. For the shiny wall the boundary layer develops on the wall side at the bottom of the radiator then starts to decrease until the top of the radiator. Almost all of the boundary layer development takes place on the radiator side. The velocity magnitude at the top of the radiator for shiny wall is higher than the velocity magnitude for black surface on the radiator hot wall side. At the same time, the velocity magnitude for the black wall is greatly higher than the shiny surface on the cold wall side. The velocity magnitude at the top of the radiator is increases, through-all the gap between hot and cold walls, as the radiator hot wall temperature increase. Also the velocity boundary layer and the velocity magnitude are increases as the radiator size aspect ratio increase.

In conclusion, this work shows that using a high radiator size aspect ratio will certainly increase the heat output from the radiator.

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Biographies

Abdulmaged Khalifa Abdullah Shati was born in Abueesa /Libya, on October 10, 1970. He received Bsc degree in Mechanical and Industrial Engineering from University of Tripoli, in 1994. He got Msc degree in Propulsion theory of Aeronautics and Astronautics from BUAA University, China in 2001. Moreover, he got PhD degree in Mechanical Engineering in the area of Thermo-fluid "Heat transfer in cavities" from the University of Sheffield/UK in 2013, where he is currently lecturer in Department of Mechanical and Industrial Engineering at University of Zawia/Libya. His research field is Thermo-fluid with CFD modeling.