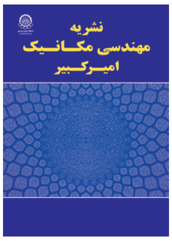

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Numerical Study of the Effects of Speed and Place of Ceiling Fans on Thermal Comfort and Reducing Energy in Office Buildings

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ABSTRACT: The main aim of the present study is to investigate the effects of speed and place of ceiling fans on thermal comfort parameters (predicted mean vote and predicted percentage of dissatisfied) and energy expenses in two different office rooms with a certain geometry in winter using district heating system. In all of the models, the regime of a flow is turbulent and governing equations are solved by finite volume method and SIMPLE algorithm. Based on the results, using ceiling fans in winter (heating system) has a considerable influence on the improvement of buildings thermal comfort and reducing consumption of energy. By using ceiling fans the effective temperature of room increases and therefore radiator energy consumption decreases. Furthermore, the results show that the location of ceiling fan does not have any effect on room effective temperature and residents' thermal comfort. According to the results, predicted mean vote and predicted percentage of dissatisfied parameters improve by turning ceiling fans on and increasing fan normal air velocity. But, the operation of fan leads to cooling system after a certain velocity and it is not acceptable for the heating system. Finally, the CF.A case with $p(x)$=1.0 m, V=0.2 m/s and $T_{radiator}$=51°C, and CF.B.1 case with $p(x)$=2.5 m, V=0.27 m/s and $T_{radiator}$=37°C, by providing thermal comfort conditions and reducing consumption of energy about 58% and 73%, respectively are reported as optimal cases.

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1- Introduction

The researchers by comprehensive studies have found that the humans spend 80 to 90% of their life in internal environments. Therefore the thermal comfort has a direct effect on human efficiency. One of the appropriate techniques to provide the thermal comfort and decrease energy consumption in the heating systems is using the ceiling fans. However, these ceiling fans support the cooling systems more than the heating systems [1,2]. Most ceiling fans use a little amount of energy although their role is completing the ventilating system. Nevertheless, the ceiling fans can also be used to help the thermal system efficiency. The ceiling fans are not only effective in saving energy but also they are effective in providing thermal comfort inside the buildings. Few studies have been carried out for the case of ceiling fans to reduce the energy consumption and provide thermal comfort in winter [3,4].

In most studies, the effects of ceiling fans on energy consumption and thermal comfort conditions during summer (cooling system) have been studied. In all of the investigations for both the thermal comfort and reducing energy consumption, the outside conditions have attracted more attention and for the internal conditions, the available standards have been used.

In the present study, the effects of using the ceiling fans on the flow and heat transfer field during winter (heating system) and also the effects of its location and velocity have been studied in order to achieve the thermal comfort and energy consumption efficiency. Hence, the results that include local velocity in the room, effective temperature, energy consumption of radiator, and Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) to the thermal conditions are reported.

2- Physical Model

In this study, ten cases were used to investigate the influence of using the ceiling fan and optimization its location and velocity. Also, for a simpler simulation, the effect of that model has been used instead of fan modeling, so that according to real dimensions of fan and the operation type in winter condition, some parts of the room have been modeled in a way that the air inside the room is sucked upward and spread to other parts of the room. The fan speed is set based on air suction speed.

The two-dimensional schematic diagrams of the modeled rooms that have a ceiling fan and the air circulation type by the fan during winter (heating system) have been shown in Fig. 1.

3- Governing Equations

PMV and *PPD* are two important indexes to estimate the human thermal comfort in buildings and these two parameters should be analyzed and calculated by Eqs. (1) and (2).

$$\begin{aligned} PMV &= \left[0.303\exp(-0.036M)+0.028\right]\cdot\{(M-W) \\ &-3.96\cdot 10^{-8} f_{cl}\left[(T_{cl}+273.15)^4-(T_r+273.15)^4\right] \\ &-f_{cl}\cdot h_c(T_{cl}-T_{air}) \\ &-3.05\left[5.733=0.007(M-W)-0.001p_w\right] \\ &-0.42\left[(M-W)-58.15\right] \\ &-0.0173M(5.867-0.001p_w) \\ &-0.0014M(34-T_{air})\} \end{aligned} \quad (1)$$

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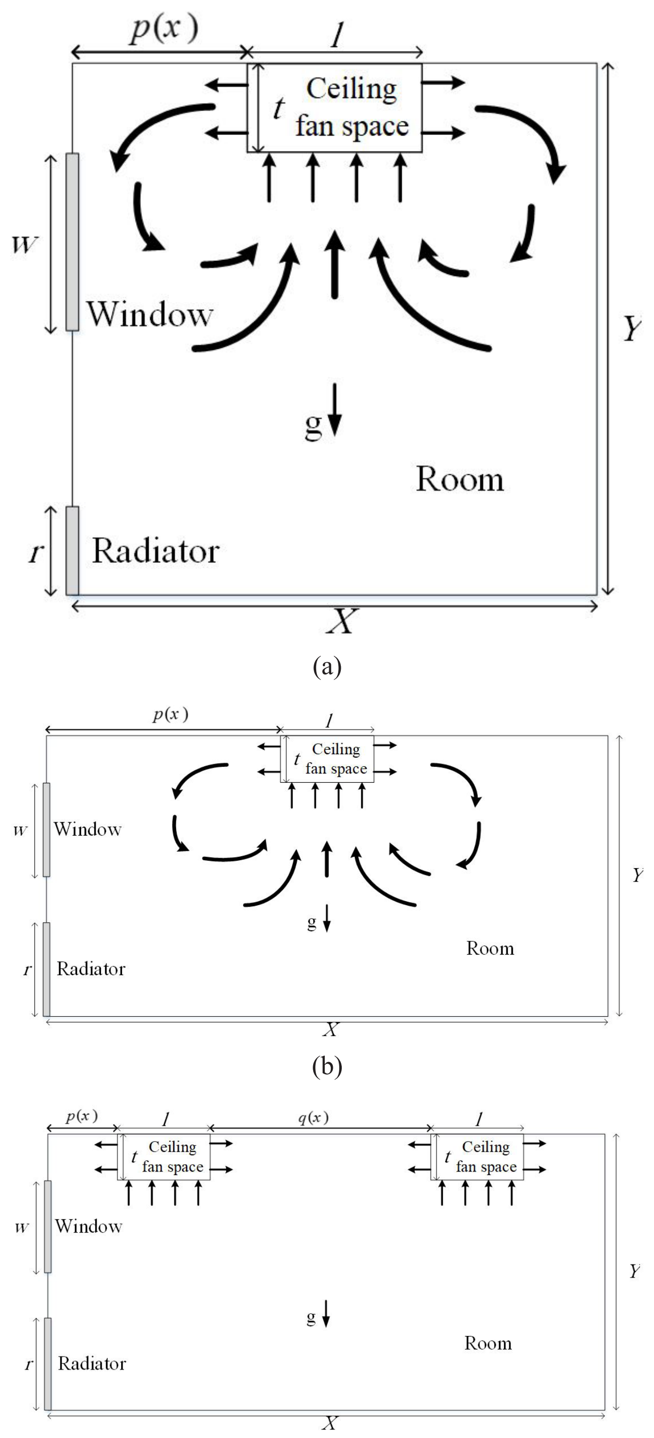

Figure 1. Schematic diagram of the modeled rooms: (a) Case A, (b) Case B.1 and (c) Case B.2.

$$PPD = 100 - 95\exp(-0.03353 \cdot PMV^{4} - 0.2179 \cdot PMV^{2}) \quad (2)$$

4- Results and Discussion

Considering the room relative humidity is 35%, the *PMV* and *PPD* diagrams are shown in Fig. 2 based on the metabolic rate of light activity (1.75 met), and the amount of thermal insulation worn by a person (1.7 clo) according to variation in fan normal air velocity for case CF.B.1 with $p(x)$=1.5 m in two different radiator temperatures. As seen in Fig. 2(a), if the fan is off in two cases of radiator temperature, the *PMV* is out of acceptable range. While the ceiling fan is turned on and the velocity increases, the *PMV* increases too and reaches to the proper range. The radiator temperature of 42°C is proper for the case when saving energy is not important. However, when the energy saving is important, the radiator temperature is 37°C. According to Fig. 2(a), for the speeds that are higher than the reported maximum speeds, increasing the fan speed leads to decreasing in *PMV* and therefore the *PMV* value will be out of acceptable range. This is because the ceiling fan performance turns to cooling at higher speeds. Moreover, Fig. 2(b) demonstrates that in the reported speeds for two temperature cases the lowest *PPD* is obtained. Furthermore, it is observed that the *PPD* with regard to using the radiator in temperature of 42°C is acceptable in the wider range of fan normal air velocity while by using the radiator with the temperature of 37°C, the thermal comfort criterion of *PPD* is provided and the energy consumption is also reduced.

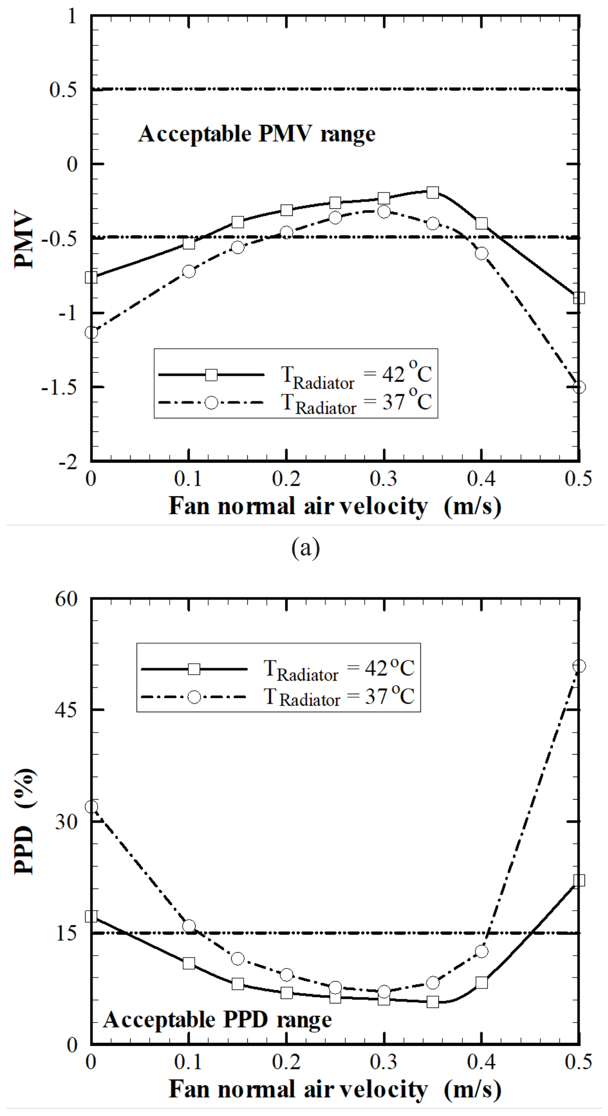

Figure 2. The effect of the radiator temperature at different fan normal air velocities on (a) *PMV*, (b) *PPD*, for case CF.B.1 with $p(x)$=1.5 m

According to the measured fan normal air velocity and based on the criterion of speeds lower than 0.25m/s in the height of 2m from the room floor, it was observed that *PMV* and *PPD* are inappropriate criteria for providing thermal comfort alone and each of the five parameters that include general indexes of thermal comfort should be analyzed specifically. Also, it was seen that using the ceiling fans eliminates the temperature gradients inside the room and makes the temperature uniform in different parts of the room, thus the temperature in occupied parts by the residents increases.

5- Conclusions

According to the results of this study, using ceiling fans in winter (heating system) has a considerable influence on the improvement of buildings thermal comfort and reducing consumption of energy. By using ceiling fans the effective temperature of room increases and therefore radiator energy consumption decreases. Furthermore, the results show that the location of ceiling fan does not have any effect on room effective temperature and residents' thermal comfort. According to the results, *PMV* and *PPD* parameters improve by turning ceiling fans on and increase fan normal air velocity. But, the operation of fan leads to cooling system after a certain velocity which is inappropriate for the heating system. Finally, the CF.A case with $p(x)$=1.0 m, V=0.2 m/s and $T_{radiator}$=51°C, and CF.B.1 case with $p(x)$=2.5 m, V=0.27 m/s and $T_{radiator}$=37°C, by providing thermal comfort conditions and reducing energy about 58% and 73%, respectively are reported as optimal cases.

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