International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

Research Article

Influence of Ceiling fans on Space Heating

Johain J. Faraj†*

†Refrigeration Dep., Middle Technical Univ., Baghdad, Iraq

Accepted 14 April 2016, Available online 16 April 2016, **Vol.6, No.2 (April 2016)**

Abstract

Simple equations was devised to get a preliminary insight into the effectiveness of ceiling fans in removing temperature stratifications developed naturally in heated spaces. The model was also used to assess the consequences of temperature stratification. Exergy relations were derived based on the one-dimensional model to analyze the problem from exergy destruction perspective. Temperature measurements in a heated space middle plane reveal high-temperature stratifications. About 40% reduction in temperature stratification was measured after using ceiling fan.

Keywords: *Ceiling fan, heating, exergy, temperature, stratification*

1. Introduction

Ceiling fans are used extensively in cooling seasons with an expected 10-15% energy savings. However, their use in winter may reduce heating costs by about 20-30% (Sadaka and Pierce). In fact, they were used whenever a positive temperature gradient exists, as such their usage spanned residential, industrial, commercial, and agricultural environments (Teitel and Tanny, 1996). (Liang, 2013) reported earlier studies in the application of ceiling fans in broiler houses. Temperature differences in the order of 10°C between floor and ceiling were reported depending on the methods and quantities of ventilation and heating sources. Also, a ceiling fan effectiveness of reducing floor – ceiling temperature differences to as much as 15°C were recorded. (Ankur *et al*., 2004) investigated experimentally air flow distribution induced by ceiling fans. They also introduced winglets and spikes to fan blades resulting in 13% further fan performance improvement. (Bassiouny and Korah, 2011) studied numerically fan Induced air flow field and presented analytical formulas for air velocities. (Cross *et al*., 2014) devised a sophisticated control system to control simultaneously many heating elements along with many ceiling fans to their optimum usage with low energy consumption.

2. Temperature Stratification

The nature of the heating process during winter produces an undesirable natural convection currents towards the ceiling. Therefore; temperature stratification is common among heated buildings in which air temperature is usually higher close to the ceiling than that close to the floor. Consequently, more heat is required to maintain the desired floor temperature level and cover the increased heat losses due to conduction through ceiling and walls as well as ventilation. Ceiling fans are widely used to overcome this problem by providing sufficient dynamic forces pushing downward hot air against buoyant forces. (Sadaka and Pierce) recommended setting the fan to its lowest clockwise rotational speed thus avoiding undesirable effects on occupants comfort. Ceiling fans produce more uniform temperature distribution across space height. (Clark *et al.*) suggested a poultry farm preparation procedure for winter season using ceiling fans to minimize energy consumption.

(Bottcher *et al*., 1988) listed many factors affecting the development of temperature stratification including space geometry, surfaces area and temperature, infiltration and ventilation rates, air velocities and properties, outside environment, type of heaters and their positions. Nevertheless; (Teitel and Tanny, 1996) suggested a simplified one-dimensional model to estimate the surplus heat needed and the energy required for mixing per air change assuming linear temperature profile as follows:

$$T = T_{floor} + \dot{T}h \quad (1)$$

Energy needed for air mixing

$$E_{mix} = \frac{gP}{2R\dot{T}^2}\left[\left(2T_{floor} + \dot{T}H\right)\ln\left(\frac{\dot{T}H}{T_{floor}} + 1\right) - 2\dot{T}H\right] \quad (2)$$

And the surplus of heat assuming constant mean density:

*Correspondig author: **Johain J. Faraj**

$$Q_{su} = \frac{PC_p(T_m - T_{floor})}{R\dot{T}} \ln\left(\frac{\dot{T}H}{T_{floor}} + 1\right) \quad (3)$$

However; this equation would not be used in this work, integration was carried out instead to get another expression for Q_{su}.

$$d(Q_{su}) = \rho C_p (T - T_{floor}) dh \quad (4)$$

Using ideal gas law for the density and rearranging

$$Q_{su} = \frac{PC_p\dot{T}}{R} \int_0^H \frac{h}{T_{floor} + \dot{T}h} dh \quad (5)$$

Integrating

$$Q_{su} = \frac{PC_p}{R}\left[H + \frac{T_{floor}}{\dot{T}} \ln\left(\frac{T_{floor}}{T_{floor} + \dot{T}H}\right)\right] \quad (6)$$

Which gives slightly lower values for the surplus heat than equation (3) of (Teitel and Tanny, 1996) as shown in fig. 1.

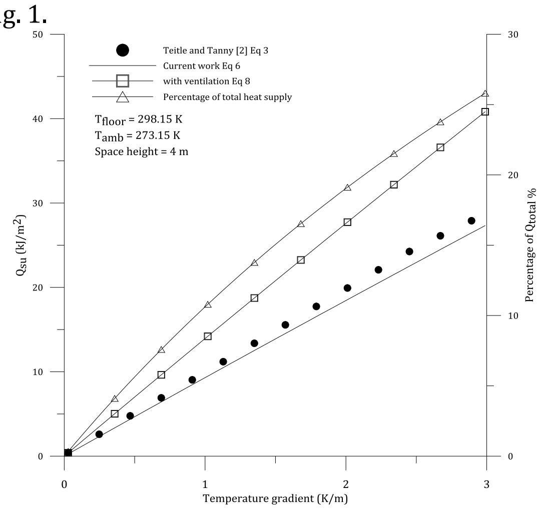

Fig. 1 Heating load

Then the total heat required is

$$Q_{total} = Q_{su} + \frac{PC_pH}{R} \frac{(T_{floor} - T_{amb})}{T_{floor}} \quad (7)$$

The surplus heat required should be modified to account for the ventilation assuming complete air extraction is at ceiling conditions:

$$Q_{su} = \frac{PC_p}{R}\left[H + \frac{T_{floor}}{\dot{T}} \ln\left(\frac{T_{floor}}{T_{floor} + \dot{T}H}\right) + \frac{\dot{T}H}{T_{floor} + \dot{T}H}\right] \quad (8)$$

Still the additional conduction losses are not accounted for in equation 8. The new surplus heat supply is shown in fig. 1 along with its percentage. It made a noticeable portion when the temperature gradient elevated while the energy required for mixing is negligible compared to it on the other hand.

The mass per unit area of air could be calculated by integrating the density multiplied by an infinitesimal element height over the whole space height.

$$dm = \frac{P}{RT} dh = \frac{P}{R}\left(\frac{dh}{T_{floor} + \dot{T}h}\right) \quad (9)$$

Thus

$$m = \frac{P}{R\dot{T}} ln\left(\frac{T_{floor} + \dot{T}H}{T_{floor}}\right) \quad (10)$$

Or, when the air is fully mixed

$$m = \frac{PH}{RT_{floor}} \quad (11)$$

The exergy analysis is a more suitable tool to investigate this problem, hence; equations regarding the exergy destruction for the two cases were arranged as follows:

For the unmixed air

$$Ex_d = (Ex_1 - Ex_2)m + Q_{total}\left(1 - \frac{T_o}{T_1}\right) \quad (12)$$

And for the mixed air

$$Ex_d = (Ex_1 - Ex_m)m + Q\left(1 - \frac{T_o}{T_1}\right) + E_{mix} \quad (13)$$

Where the thermomechanical exergy is defined as (Querol, 2013):

$$Ex = C_p\left[(T - T_o) - T_o ln\left(\frac{T}{T_o}\right)\right] \quad (14)$$

Noting that the subtraction of E_{mix} in equation 13 is changed to addition accounting for the sign of work itself since it is done on the system. The exergy transfer accompanying heat transfer is computed at temperature T_1 (the average temperature at which heat is supplied) (Gundersen, 2011), (Moran *et al.*, 2011). Applying these equations to the same conditions above reveals that the destruction of exergy rapidly builds up with the temperature gradient for the unmixed case, as shown in fig. 2. Hence; even though the exergy destruction for the mixed case also increases with temperature gradient but still well below the unmixed case.

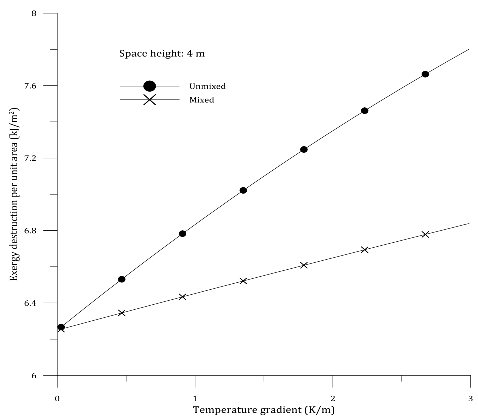

Fig. 2 Exergy destruction

3. Space measurement

A full scale residential space with dimensions of 5 m width, 2.8 m depth, and 2.9 height was chosen to investigate ceiling fan influence on temperature stratification as shown in fig. 3. The fan is mounted in the middle of space with features presented in table 1. The fan was not complying completely with winter recommendations, nevertheless; the experiment was conducted. The schematic shows the measurement plane, hot air inlet, air outlet, and the window and door locations. The space is a living room occupied by about 6 to 7 persons, and the door is almost open. The wall containing the window is an outer wall facing west. The wall holding the door and the east wall are inner walls. The supply vent (0.5m width, 0.1m height) is located at about 1 m apart from the north wall and at 2.3 m above ground.

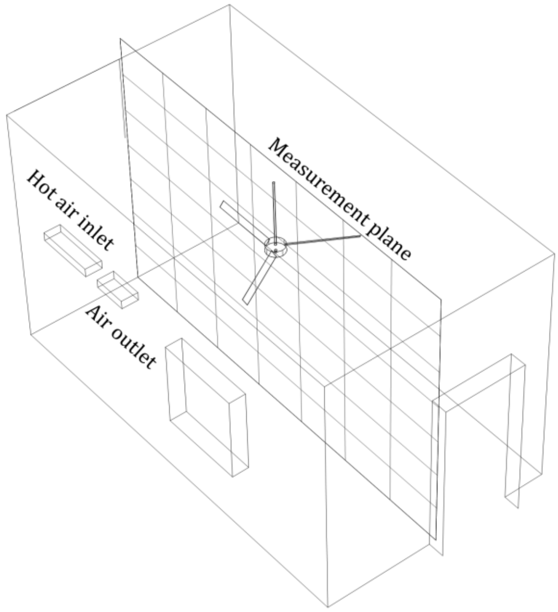

Fig. 3 A schematic of the test space

Table 1 Ceiling fan specifications

Feature	*Recommendations*	*Current*
Height above floor	2.4 – 2.75 m (energy star 2016)	2.1 m
Blade span for (14 m^2 floor area)	1.12 (energy star 2016)	0.61 m
Rotation direction	Clockwise (Sadaka and Pierce)	Anti- clockwise
Angular velocity (RPM)	Lowest (Sadaka and Pierce)	30

The outlet vent is located at 0.1 m from the supply vent. The hot air was supplied at about 1 m/s velocity and 45°C temperature. The dry bulb temperature was measured throughout the middle plane using thermocouples and data logger. The hot air supply was turned off after 25 minutes after which, the ceiling fan was turned on.

4. Results and discussion

The initial temperature distribution was measured before turning on hot air supply as displayed in fig. 4. Initially, the temperature is almost uniform within about 3°C margin. After supplying the space with hot air for 15 minutes, the temperature distribution became as shown in fig. 5.

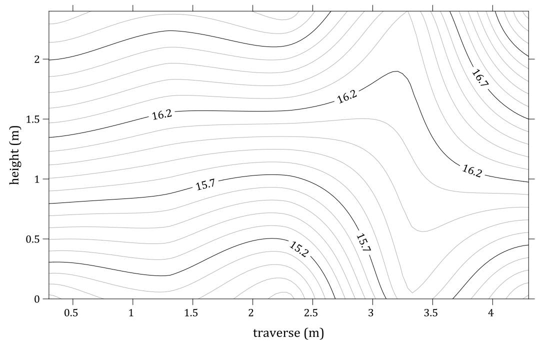

Fig. 4 Initial temperature contours

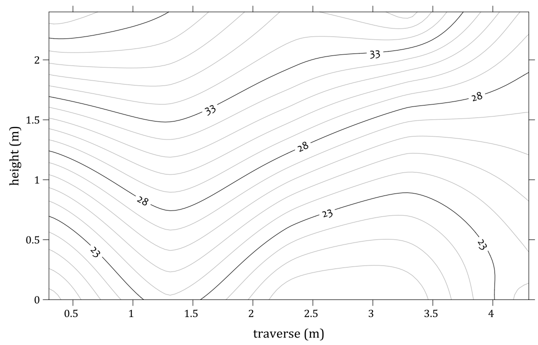

Fig. 5 Temperature contours after 15 minutes.

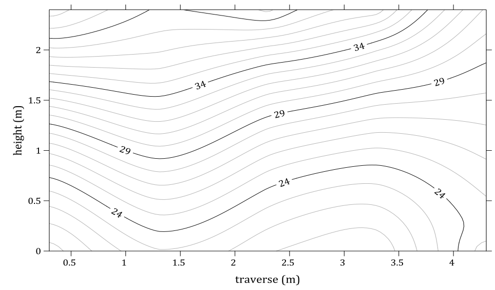

Fig. 6 Temperature contours after 25 minutes

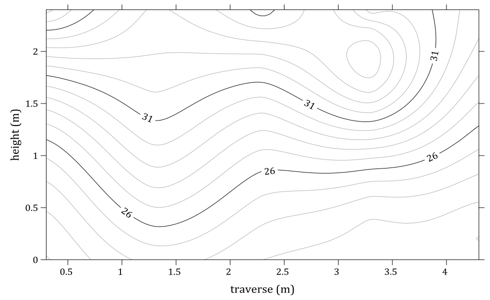

Fig. 7 Temperature contours after 5 minutes of fan operation

A strong temperature stratification is generated with high-temperature spots in front of the supply vent. Low temperature area appears as well in front of the window and near the door caused by infiltration. Fig. 6 shows the temperature distribution after 25 minutes in which the hot spots became broader. Meanwhile, the cold regions began to diminish. Apparently, the ceiling fan is justified in such conditions. At this time, the hot air supply was shut off, and the ceiling fan was turned on. After a period of 5 minutes elapsed, a more uniform distribution produced with some persistent hot spots with lower temperature, though, as shown in fig. 7. An additional 5 minutes period depicted the effectiveness of the ceiling fan (fig. 8) in spite of cold regions commenced to grow up adjacent to the north exterior wall and near the door and window. It is worth mentioning that the remaining stratification may be attributed to low fan speed, its rotational velocity direction, and size which is below recommendation (table 1). According to (Ankur *et al.*, 2004), only 75% of blade span effectively contributes to air movement.

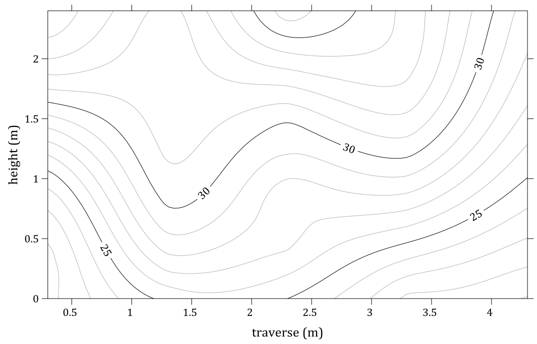

Fig. 8 Temperature contours after 10 minutes of fan operation

Fig. 9 summarizes the overall operation, a strong temperature stratification built up during hot air supply period while the ceiling fan effectively mixes the air and reduces the stratification by about 40%.

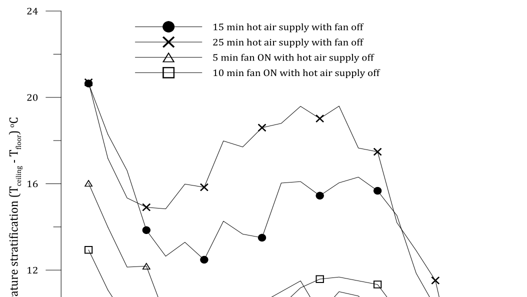

Fig. 9 Temperature stratification

Conclusions

1) The surplus heat required constitute an appreciable percentage from the total supplied heat according to the one dimensional model.
2) From exergy destruction perspective, the use of ceiling fan is justified even for small temperature gradients.
3) Depending on the heat supply source type, position and other specifications, a temperature stratification in the order of 10°C may be produced.
4) The ceiling fan is an effective method to reduce temperature stratification.
5) Using fans comply with the recommendations may give better results.

Notations

A area [m^2];
C_p specific heat for constant pressure [kJ/kg K];
E_{mix} energy required for mixing per unit area [kJ/m^2];
Ex Exergy per unit area [kJ/m^2];
Ex_1 Exergy of inlet stream per unit area [kJ/m^2];
Ex_2 Exergy of outlet stream per unit area [kJ/m^2];
Ex_d Exergy destruction per unit area [kJ/m^2];
g acceleration due to gravity [m/s^2];
h distance from the floor [m];
H space height [m];
m mass of air per unit area [kg/m^2];
P Pressure [kPa];
Q_{su} Surplus heating load per unit area [kJ/m^2];
Q_{total} Total heating load per unit area [kJ/m^2];
R Air gas constant (=0.287) [kJ/kg K];
T_{amb} Ambient air temperature [K];
T_{floor} Air temperature at floor level [K];
T_m Bulk temperature (mass averaged) [K];
T_o Temperature of standard conditions (=25°C) [K]; and
$\dot{T}$ Temperature gradient [K/m];

References

R.W. Bottcher, G.R. Baughman and L.B. Driggers, (1988), Temperature stratification in broiler houses and the effect of ceiling fans, Applied *Engineering in Agriculture,* vol.4, no. 1, pp. 66-71.

M. Teitel, and J.Tanny, (1996), A note on energy saving in heated enclosures, *Building and Environment,* vol. 31, no.6, pp. 537-540.

J. Ankur, R. R. Upadhyay, S. Chandra, M. Saini, and S. Kale, (2004), Experimental Investigation of the Flow Field of a Ceiling Fan, *ASME Heat Transfer/Fluids Engineering Summer Conference Proceedings,* vol. 3, pp. 93-99.

R. Bassiouny, and N. S. Korah, (2011), Studying the features of air flow induced by a room ceiling-fan, Journal *of Energy and Buildings,* vol. 43, no. 8, pp. 1913-1918.

T. Gundersen, (March 2011), Introduction to Exergy and Energy Quality, *Norwegian University of Science and Technology/ Department of Energy and Process Engineering*, 4.

M.J. Moran, H.N. Shapiro, D.D. Boettner and M.B. Bailey, (2011) Fundamentals of Engineering Thermodynamics, 7th, *Wiley Publishing*, pp. 423-359.

Liang, Yi, (2013), Estimating Fuel Savings by Ceiling Fan Operation, *University of Arkansas Systems/ Division of Agriculture*, 9.

E. Querol, B. Gonzalez and J.L. Perez, (2013), Practical approach to exergy and thermo-economic analyses of industrial processes, *Springer Briefs in Energy XIV*, ISBN 978-1-4471-4621-6, vol. 84, p.19.

ENERGY STAR (1 March 2016), Ceiling Fan Basics: Choosing the Right Size, 〈http://www.energystar.gov/products/lighting_fans/ceiling_fans/ceiling_fan_basics〉.

A. Cross, K. Hammer, R. Hurt and R. F. Boehm, (2014), An Autonomous Controller for Ductless Mini-Split Heat Pumps, Residential Solar Thermal Collection, and Hydronic Floor Heating, *ASME 8th International Conference on Energy Sustainability collocated with the ASME 12th International Conference on Fuel Cell Science Engineering and Technology Proceedings* 2: Paper No. ES2014-6316, V002T10A002.

Sadaka, S. and K. Pierce, (Accessed 2016), Ceiling Fans, *University of Arkansas/Division of Agriculture,* FSA1053.

F. D. Clark, J. Moyle, K. Bramwell and T. Tabler, (Accessed 2016), Winterization Suggestions for the Poultry Farm, *University of Arkansas/ Division of Agriculture* FSA8009 - PD-1-13N.