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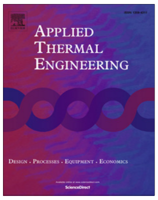

Research Paper

Energy saving and indoor thermal comfort evaluation using a novel local exhaust ventilation system for office rooms

Ahmed Qasim Ahmed [a,b,*], Shian Gao [a], Ali Khaleel Kareem [a]

[a] *Department of Engineering, University of Leicester, Leicester LE1 7RH, United Kingdom*
[b] *Engineering Technical College, Middle Technical University, Baghdad, Iraq*

HIGHLIGHTS

- A new system of local exhaust ventilation for offices (LEVO) was developed and validated successfully.
- The novel LEVO system was used to evaluate effectively the indoor thermal environment and energy savings.
- The new system was found to reduce the contaminant concentration in a micro-environment area by up to 61%.
- By using the LEVO system, up to 30% of energy savings were achieved.

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ABSTRACT

Energy saving, indoor thermal comfort and inhaled air quality in an office are strongly affected by the flow interaction in the micro-environment around the occupants. The local exhaust ventilation system, which aims to control the transmission of contaminant and extract contaminant air locally, is widely used in industrial applications. In this study, the concept of the local exhaust ventilation system is developed for use in office applications. Consequently, a novel local exhaust ventilation system for offices was combined with an office work station in one unit. Energy saving, thermal comfort and inhaled air quality were used to evaluate the performance of the new system. Experimental data from published work are used to validate the computational fluid dynamic model of this study. The performance of the new system for three different amounts of recirculated air (35%, 50%, and 65% of the total mass flow rate) was investigated numerically in an office room with and without using the new system to show its impact on energy saving, thermal comfort and inhaled air quality. The result shows that the new local exhaust ventilation system can reduce the energy consumption by up to 30%, compared with an office not using this system. Furthermore, this system was able to reduce the contaminant concentration in a micro-environment area by up to 61% and improve the human thermal comfort in the occupied zone. It can be concluded that using the local exhaust ventilation concept can make significant improvements to the quality of inhaled air and produce extra energy saving with an acceptable thermal comfort.

1. Introduction

Most people spend the majority of their time indoors [1–3]. Therefore, Indoor Air Quality (IAQ) and human thermal comfort should be maintained at a high level. In recent decades, various ventilation methods and devices have been developed to provide a comfortable thermal environment for occupants and to reduce the demand for energy [4–7]. In addition, one of the most important strategies is to use a Local Exhaust Ventilation (LEV) system, also called the Personalised Exhaust (PE) system. In this system, warm and contaminated air is extracted locally before reaching the occupied area, which consequently enhances the quality of the inhaled air. The LEV system is not a new method of ventilation. It is used to control the contaminant transmission in occupied areas [8–11] and has been widely used in industrial applications to provide a healthy and comfortable work space. Melikov et al. [12] used an LEV concept to develop the thermal environment around a hospital bed and investigated the reduction of the exposure for the doctor and the patient with and without the LEV system. They found that with the LEV system the exposure level was reduced significantly for people who sat close to the patient. Dygert and Dang [9] proposed to use a local exhaust

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[*] Corresponding author at: Department of Engineering, University of Leicester, Leicester LE1 7RH, United Kingdom.

E-mail addresses: aqaa2@le.ac.uk, en_ahmed82@yahoo.com (A.Q. Ahmed).

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Nomenclature

Abbreviations

DV	Displacement Ventilation
IAQ	Indoor Air Quality
LEV	Local Exhaust Ventilation
LEVO	Local Exhaust Ventilation for Office
PMV	predicted mean vote
PPD	predicted percentage of dissatisfied
STRAD	Stratified Air Distribution System

Latin letters

C	mean particle concentration (kg/m^3)
$C_{1\varepsilon}, C_{2\varepsilon}$	model constants in the term ε of the turbulence model
C_n	normalised concentration
C_p	contaminant concentration in a specific region (kg/m^3)
C_e	the concentration at exhaust (kg/m^3)
C_μ	model constant of the turbulence model
c_p	specific heat of air at constant pressure (J/(kg K)
d_p	particle diameter (m)
dt	particle residence time (s)
$\underline{F}_D$	inverse of relaxation time (s^{-1})
$\underline{F}_a$	force acting on particle (m/s^2)
$\underline{F}_b$	Brownian force (m/s^2)
$\underline{F}_{thermal}$	thermophoretic force (m/s^2)
$\underline{F}_s$	Saffman's lift forces (m/s^2)
$\vec{g}$	gravitational acceleration (m/s^2)
i	trajectory index
j	cell index
k	turbulent kinetic energy per unit mass (J/kg)
$\dot{m}$	mass flow rate associated with each trajectory (kg/s)
$\dot{m}_e$	exhaust mass flow rate (kg/s)
n	trajectory number
P_k	additional term in the turbulence model
$Q_{coil-STRAD}$	cooling coil load for the STRAD system (W)
Q_{space}	cooling coil load of space (W)
Q_{vent}	ventilation load (W)
$Q_{coil-MV}$	cooling coil load for the mixing ventilation system (W)
S	mean strain rate tensor magnitude
S_{ij}	strain rate tensor
T_e	the exhaust temperature (°C)
T_{set}	room set temperature (°C)
t	time (s)
$\vec{u}_p$	particle velocity vector (m/s)
u	fluid velocity (m/s)
u'_i	fluctuating velocity (m/s)
V_j	volume associated with i trajectory and cell j

Greek letters

β	coefficient of thermal expansion (1/K)
ε	turbulent dissipation rate (m^2/s^3)
λ	represents the molecular mean free path
μ	dynamic viscosity (kg/(m s)
ξ_i	normally distributed random number
ρ	fluid density (kg/m^3)
ρ_p	particle density (kg/m^3)
σ_k	model constant for k equation of the turbulence model
σ_ε	model constant for ε equation of the turbulence model

suction device in an airplane, and their results showed that up to 90% reduction of exposure to contamination comes from other passengers. Furthermore, they concluded that this type of LEV is suited to a high density occupation. Zítek et al. [11] investigated the thermal environment and the air quality around the occupants in an aircraft using a separate air flow supply and a separate local exhaust. Their results showed that using this system protected the occupants from possible dispersion of disease in an aircraft environment. Qian et al. [13] considered the pollutant transmission in a hospital ward using a downward ventilation system. They found that the fine particle removal efficiency was improved by using an exhaust at a high level, while locating the exhaust at a low level improved the particle removal efficiency for large-size particles. Cheong and Phua [14] examined the performance of contaminant removal using different strategies of ventilation system in hospital rooms. They found that the best performance in contaminant removal occurred by situating the supply and exhaust diffuser on the wall behind the patient's bed. Neilsen et al. [15] studied the risk of cross-contamination in a hospital room using a downward ventilation system. They revealed that the position of the return openings played a significant role in the transmission of exhaled contaminants in the room. Yang et al. [16] researched the performance of three different kinds of personalised exhaust (PE) device. They found that the quality of the inhaled air was enhanced by using a PE just above the occupant's shoulder level. Bolashikov et al. [17] explored the thermal environment around the occupant by combining the local exhaust with a local supply using a seat-incorporated with a Personalised Ventilation (PV) unit. They found that using this system enabled them to enhance the quality of the inhaled air. Junjing et al. [18] looked into the performance of contaminant removal effectiveness at 12 different locations by using a PE-PV system installed on the chair above the occupant's shoulder level. They found that using this system enhanced the inhaled air quality for the seated persons compared with using a PV system alone.

The previous studies focused on using a LEV system in hospitals rooms, airplanes and on some industrial applications to improve the quality of the inhaled air and provide a healthy and comfortable environment for the occupants. However, very limited studies have considered the LEV as a ventilation system in an office space [16,17], and its impact on the energy consumption. Therefore, in this study a novel ventilation system, the Local Exhaust Ventilation for Office (LEVO) system, was investigated numerically to show the effects of using this system on the energy saving and thermal environment around the occupants. In general, most indoor contaminants in an office arise from furniture, work station equipment and by occupants' activities and may contain chemical substances [19,20]. Therefore, in this study the contaminants were released from two pollutant sources: one is located at the work station in front of each occupant to simulate contaminants coming from office equipment and the other is from the occupants' work activities.

2. Methods

The main objectives of the proposed LEVO air distribution system are to improve the energy saving and provide a healthy and comfortable local environment around the occupants by controlling the heat convection resulting from the room heat sources, i.e. the thermal plumes generated by the occupants and other heat sources. Fig. 1. shows schematic diagrams of (a) the LEVO combined with the office workstation, (b) air flow direction around the occupants in a room using the LEVO system, (c) the details of the simulated room, and (d) the arrangement of the simulated room. A numerical investigation of the combination between the lamps and exhaust opening was performed by the current authors