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A study of the effect of heat source location in a ventilated room using multiple regression analysis

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Abstract

Multiple regression analysis is a statistical technique which allows to predict a dependent variable from more than one independent variable and also to determine influential independent variables. Using experimental data, in this study the multiple regression analysis is applied to predict the room mean velocity and determine the most influencing parameters on the velocity. More than 120 experiments for four different heat source locations were carried out in a test chamber with a high level wall mounted air supply terminal at air change rates 3–6 ach. The influence of the environmental parameters such as supply air momentum, room heat load, Archimedes number and local temperature ratio, were examined by two methods: a simple regression analysis incorporated into scatter matrix plots and multiple stepwise regression analysis. It is concluded that, when a heat source is located along the jet centre line, the supply momentum mainly influences the room mean velocity regardless of the plume strength. However, when the heat source is located outside the jet region, the local temperature ratio (the inverse of the local heat removal effectiveness) is a major influencing parameter.

Keywords: Heat source locations; Plumes; Mixing ventilation; Room velocity; Multiple regression analysis

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1. Introduction

The room velocity, i.e., mean velocity in the occupied zone (U_{oc}), has a major influence on ventilation performance and thermal comfort in mixing ventilation. This velocity depends on the ventilation parameters such as jet momentum, Archimedes number, ventilation load, etc.

Most published research [1–4] on the relationship between the ventilation parameters and room mean velocity has applied the simple regression approach. The simple regression approach mainly concerns the relationship between one parameter and room mean velocity. In order to predict how the parameter correlates with the room velocity, the initial experimental conditions are usually required to be simplified, such as:

- Selecting a dominant air flow element for the room, e.g. *a jet* [1,2,4],
- Excluding heat sources in the room by considering isothermal condition [1,2,4],
- Considering the effect of room load on the mean velocity using hot/cold surfaces [5–7].

Such a simple regression method may not be applicable in a practical situation that has more than one flow element (e.g. a cold air jet supply and a plume from a heat source). In cases with heat sources in the room, the room velocity (U_{oc}) and the internal thermal conditions are influenced by the location as well as the strength of the heat sources which would be difficult to determine using traditional methods.

The interaction between the jet and plumes from heat sources has been previously investigated with a constant plume strength [8,9]. However, when the room velocity (U_{oc}) is compared for different heat source locations, the effect of parameters (such as thermal load and ventilation load) is not easy to predict due to the changes in the internal thermal conditions as a result of the change in plume strength or position. Thus, it becomes necessary to

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Nomenclature

A	area of supply device (m^2)
Ar	the Archimedes number
a	intercept
b_i	partial regression coefficient
c_p	specific heat (J/kg K)
g	acceleration of gravity (m/s^2)
F	F-statistic
H	distance between ceiling and supply device
$\mathrm{LT}_{\mathrm{ratio}}$	inverse of local heat removal effectiveness
l_c	characteristic length (m), $= \sqrt{A}$
M_{o}	supply momentum (N)
n	sample size
Q_{heat}	heat load (W/m^2)
Q_{vent}	ventilation load (W/m^2)
R^2	coefficient of determination
R^2_{ind}	individual R^2
T_i	supply temperature (K)
T_o	extract temperature (K)
T_{p}	mean vertical temperature along the heat source centreline (K)
ΔT	temperature difference, T_{o}—T_{i}
u_i	supply velocity (m/s)
U_{oc}	room velocity (m/s)
$\hat{U}_{\mathrm{oc}}$	predicted room velocity (m/s)
VIF	variance inflation factor
$\dot{v}$	supply flow rate (m^3/s)
X_i	independent variables
Y	dependent variable
$\hat{Y}$	predicted value of Y
$\bar{Y}$	mean of Y

Superscript

avg	average

Greek letters

α	significance level
β	expansion coefficient (1/K)
ρ	density (kg/m^3)

conduct a number of trials for each case that represents different thermal conditions. Therefore, the multiple regression analysis is applied in this study with the following aims:

I. to determine what influencing parameters on U_{oc} are dominant.
II. to predict U_{oc} from the determined parameters.
III. to compare the predicted values of U_{oc} for different heat source locations.

2. Multiple Regression Analysis

As a way to provide a visual depiction of the concept for multiple regression analysis, a quasi Venn diagram is used to explain the shared variance in correlation or regression [10].

2.1. Anomaly of simple regression analysis

Simple regression analysis can show how a single dependent variable is affected by the values of one independent variable (Fig. 1a). This method only concerns X_i variable as a predictor (i.e., independent variable) and Y variable as an outcome (i.e., dependent variable). Thus, if two or more predictors are used for the simple regression analysis, each predictor can show separately an individual relationship with the outcome variable, e.g. U_{oc} and Q_{heat}, U_{oc} and M_{o}. Another anomaly of simple regression analysis is that it cannot predict the most significant X variable among independent variables (e.g. whether Q_{heat} or M_{o} is the most influential parameter with regard to change in mean velocity) for this situation.

2.2. Multiple linear regression model

A multiple linear regression model is generally expressed by the relationship between a single outcome variable (Y) and some explanatory variables (X_i) given as:

$$\hat{Y} = a + b_1 X_1 + b_2 X_2 + \cdots + b_n X_n, \tag{1}$$

where the term $\hat{Y}$ is the predicted value of Y (estimated from X_i), a is the intercept and b_i are the partial regression coefficients. In our case $Y = U_{\mathrm{oc}}$.

The multiple regression as shown in Fig. 1b, presents two different overlaps: the overlap for the combined effect and the overlap for the individual effect. In the assumptions of multiple regression, the relationship between variables is assumed to be linear and the residuals are normally distributed.

2.2.1. Individual effect

For the individual effect, each partial relationship with Y can give useful information on how much one factor overlaps with Y independently. Usually in statistical programs, T-value (defined as the coefficient b_i divided by its standard error) and P-value (the probability of the sample result obtained by a null hypothesis testing, refer to [10–14]) for each independent variable are produced to explain how a certain independent variable significantly influences the dependent variable.

If P-value $\leqslant 0.05$ and T-value>2 for the X_i variables, then these X_i variables can be called statistically significant,