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Research on Kitchen Environmental Improvement and Energy Saving Based on Sustainable Development

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Abstract: Sustainable development is paid more and more attention all over the world nowadays. Kitchen environmental improvement and energy saving are closely related to national economy, household consumption, and people's health, which is one of the important contents in the sustainable development. The conventional ventilation mode is only installing a range hood in a residential kitchen. The distribution law of contaminants in a residential kitchen in conventional ventilation mode is studied via experiment and numerical simulation method, and the results are shown in tables and figures in the paper. We found that locations of contaminants accumulation are high near to ceiling above the location of cooking utensil (range) in vertical planes, and closer to the walls in horizontal planes. According to the contaminant distribution patterns, for creating a clean and energy saving kitchen, this project set three different control schemes: (1) installed a range-hood only; (2) installed a range-hood and a natural air make-up system (a fresh air inlet under one of walls); (3) installed a range-hood, a natural air make-up system, and a full exhaust system (a louver in the ceiling for mechanical ventilation). The exergy intensity of multiple pollutants is adopted as an evaluation index of indoor air quality, the sustainability of each of three schemes is studied by using Analytical Hierarchy Process. Authors found that it improves indoor air quality effectively and conforms to the sustainable development strategies when the scheme 3 is proposed as an alternative of the conventional scheme 1.

Keywords: kitchen clean; exergy; natural ventilation; exhaust system; sustainable development analysis.

1. Introduction

With the improvement of the living standard, people pay more attention to indoor air quality. Cooking in residential kitchen generates significant amount of gases and particulate pollutants, and is regarded as a major pollutant source in residential microenvironments [1]. Chinese cooking normally consists of deep frying, grilling, and stir frying, which raise the chance of having cancer. Many studies have revealed that the occurrence of lung cancer among Chinese women is very high in the world and tobacco smoking is not always the primary cause [2]. At present, pollution and energy consumption in a kitchen are both serious problems, so creating a clean and energy-saving kitchen environment to satisfy the sustainable development demands becomes a hot topic in modern architecture and environment researches [3-5]. Authors researched environmental improvement and energy saving with sustainable development analysis in a kitchen. It seems scientific and reasonable that sustainable development evaluating method is more prospective and conducive to the environmental improvement and the stable development of society than traditional methods [6].

2. Methods

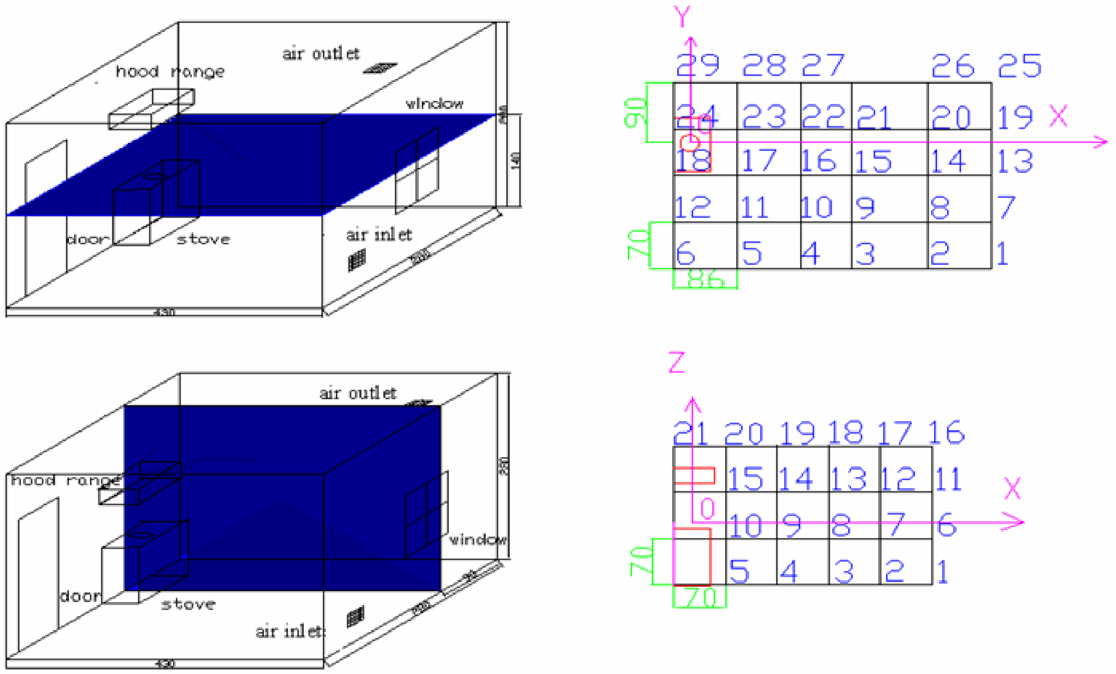
2.1. The Measurement of Kitchen Contaminants

The study is based on a Chinese kitchen established in the Artificial Environment and Energy Saving Laboratory in Shenyang Jianzhu University. The kitchen structure, the studied planes and the measured points are shown in Figure 1. The kitchen is 4.3m×2.8m ×2.8m, and the door and the window are closed. The distance between the range-hood bottom and the top plane of stove is 700mm. The volumes of the range-hood exhaust, the make-up air inlet and air outlet are 7.4 m^3/min, 2.5 m^3/min and 4.5 m^3/min, separately. The component of liquefied-gas for cook is pure propane, and French fries are made with soybean oil. TESTO400 multi-function measuring instrument and PGM-7240 VOCs detector are selected as experiment instrument to test CO, CO_2, and TVOC concentrations. The horizontal plane at the human breathing height (1.4 m) and the vertical plane through the gas fire are selected to study. The sampling points are evenly arranged in the planes.

2.2. Simulation Software Development

Based on the experimental data, the distribution mathematical models of the contaminants' concentrations, the exergy, and the exergy intensity are established via Data Fit method. On the VC++ platform, the established models are solved numerically. The simulation results are showed with the TeeChart control. The pollutant distribution simulation software with friendly and simply operating interface is developed.

Figure 1. The experimental kitchen structure, the studied planes and the measured points



2.3 Schemes

This paper sets three pollutant control schemes whose situations are listed in Table 1, for authors to research the sustainability of three schemes. The sustainability is related to many factors, indoor air quality is one of them in question here.

Table 1. Configurations of three schemes (NO means not open/operate)

Features	Range hood	Air inlet	Air outlet
(1) Conventional ventilation mode	Operated	NO	NO
(2) Effect of natural air make-up system	Operated	Operated	NO
(3) Effect of full exhaust system	Operated	Operated	Operated

3. Results and Analysis

3.1. Conventional Ventilation Mode

The actual test results of the contaminants' concentrations of the conventional scheme are shown in Table 2. The simulation results are shown in Figure 2 and Figure 3. It can be seen that air quality in the kitchen installed only a range hood is poor. Figure 2 shows in a horizontal sectional-plane at the human breathing height, the locations of contaminants' accumulation are close to the walls, which results from the boundary reflection action. It means that the pollutant concentration in place with boundary is as twice as that without boundary [7]. The very high temperature around stove makes the flow buoyancy dominant [4], so it is obvious that locations of contaminant accumulation are high near to ceiling above the location of cooking utensil (range) in the vertical planes. According to the flow patterns we discovered, we decided that a natural air make-up system (a fresh air inlet under one of walls) and a full exhaust system (a louver in the ceiling for mechanical ventilation) are installed in order to improve the kitchen environment.

Table 2. The actual test results of the contaminant concentrations

Horizontal plane points	CO (ppm)	CO_2 (ppm)	TVOC (ppb)	Vertical plane points	CO (ppm)	CO_2 (ppm)	TVOC (ppb)
1	1.8	662	619	1	1.2	696	441
2	1.0	686	608	2	0.6	500	311
3	2.7	750	873	3	2.5	430	269
4	1.3	659	576	4	0.8	543	266
5	1.1	666	661	5	0.6	415	246
6	0.9	630	510	6	0.7	568	284
7	0.8	652	434	7	1.0	433	244
8	2.1	641	525	8	0.4	407	179
9	1.2	683	378	9	0.9	502	253
10	1.1	559	288	10	1.1	576	338
11	0.1	533	354	11	1.3	696	608
12	1.0	571	314	12	0.5	787	1032
13	1.0	620	283	13	0.1	681	575
14	1.0	592	353	14	1.5	618	381
15	1.0	607	345	15	1.1	640	338
16	0.9	593	302	16	0.6	636	530
17	0.7	547	294	17	1.3	647	374
18	0.5	500	283	18	1.5	700	436
19	1.3	696	608	19	2.2	672	584
20	0.5	787	1032	20	0.8	700	483
21	0.1	681	575	21	5.6	981	2300
22	1.5	618	381				
23	1.1	640	338				
24	1.8	772	847				
25	0.7	677	524				
26	1.0	674	573				
27	2.0	678	608				
28	1.1	619	311				
29	1.2	610	851				

Figure 2. Simulation results in horizontal plane

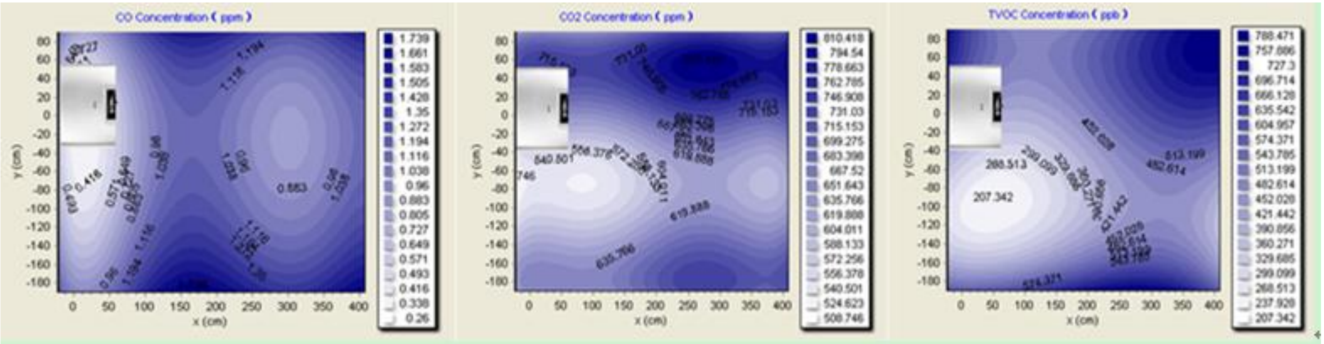
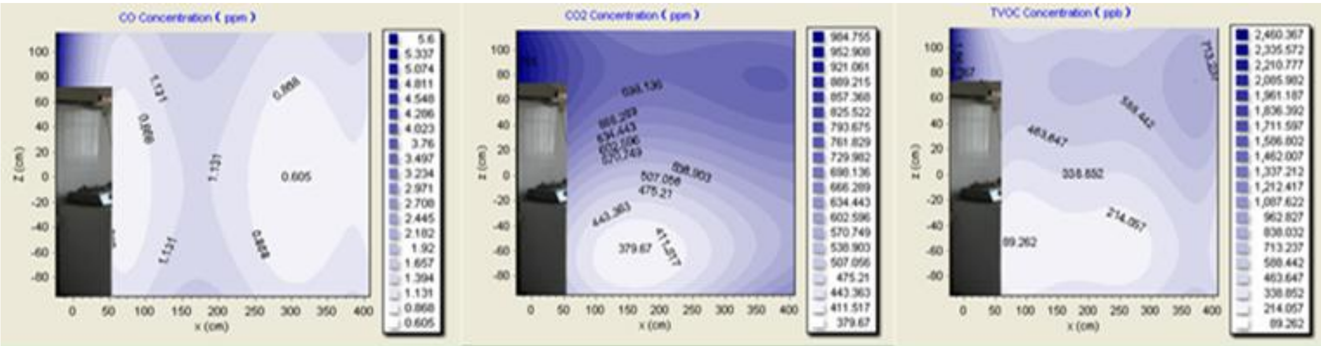


Figure 3. Simulation results in vertical plane



3.2. Evaluation of Indoor Air Quality of Three Schemes

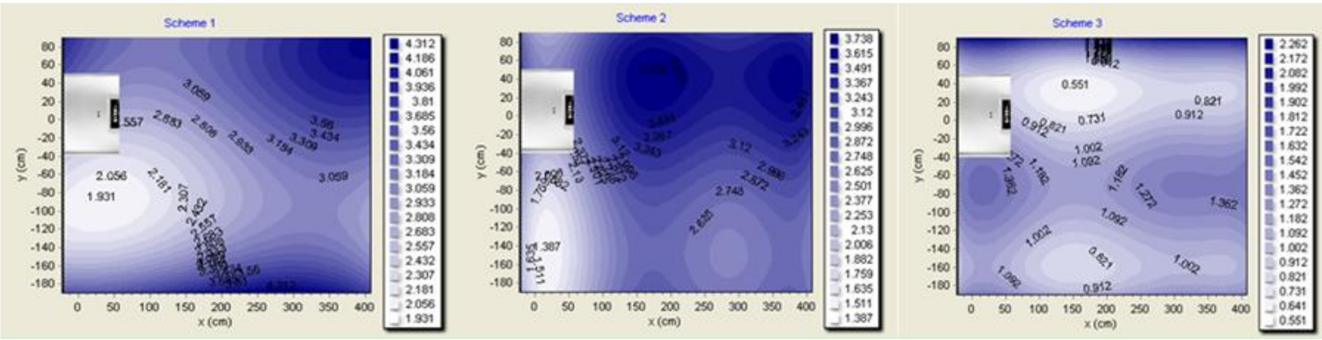
Concentration is the main evaluation index of indoor air quality at present, but because of the diversity of kitchen pollutants and the additivity of exergy, multiple exergy intensity is adopted as an evaluation index in this paper [8-9]. The horizontal planes are chosen as evaluating objects because they are in the people’ breathing zone. The multiple exergy intensity values of three schemes are listed in Table 3, from which we can see the average values are 3.17, 2.77, and 1.33 respectively. The simulation results are shown in Figure. 4. The multiple exergy intensity values of the scheme 1 are in the range of 1.931~4.312, the scheme 2 are in the range of 1.387~3.738, and the scheme 3 are in the range of 0.551~2.268. The scheme 3 is the best one for indoor air quality, the next is the scheme 2, and the scheme 1.

Table 3. The multiple exergy intensity values of three schemes in measured points

Scheme / Point	1	2	3	Scheme / Point	1	2	3
1	3.82	2.85	1.18	16	2.35	2.71	1.15
2	3.68	2.08	1.04	17	2.18	2.20	1.75
3	4.60	2.35	1.78	18	1.97	2.43	1.58
4	3.62	3.08	0.90	19	3.76	2.94	1.35
5	3.83	1.86	1.20	20	4.54	4.16	0.89
6	3.29	2.42	1.01	21	3.06	3.60	0.82
7	3.02	2.16	1.99	22	2.89	3.14	0.70
8	3.55	2.53	1.29	23	2.65	2.48	0.73

9	2.91	2.45	1.01	24	4.48	3.32	1.71
10	2.27	2.87	0.87	25	3.34	3.05	2.55
11	2.03	2.17	0.65	26	3.57	3.24	1.56
12	2.41	2.16	0.86	27	3.83	3.79	1.99
13	2.30	3.24	0.95	28	2.48	2.43	2.45
14	2.64	2.96	1.10	29	4.21	2.36	2.22
15	2.62	3.35	1.13	Average value	3.17	2.77	1.33

Figure 4. The multiple exergy intensity distributions of three schemes



3.3. Sustainable Development Analysis

The sustainable development of kitchen environmental improvement and energy saving is the overall goal. We built the index system of the sustainable development with indoor air quality, initial energy cost, working energy cost, and total generated pollution, 4 aspects. The aim is to present a relatively ideal pollutant control scheme from three ones and conform to the sustainable development. The analytical hierarchy structure of each scheme is established and shown in Figure 5. Because different factors have different effects on the overall goal, they should be multiplied by different weight coefficients. We use the Analytic Hierarchy Process to calculate the weight coefficients [10] that are listed in Table 4. The normalization equation (1) is used to eliminate the influence of different dimensions of factors [6], and the calculated values of C_{ij} are listed in Table 5. The mathematical model of sustainable development evaluation is equation (2). R in the equation represents sustainability evaluation index of a scheme. The R values of three schemes are 1, 1.012，and 1.06125, respectively. The scheme 3 is the best one for the sustainability, the next is the scheme 2, and the scheme 1.

$$C_{ij} = \frac{X_{1j}}{X_{ij}} \tag{1}$$

$$R_i = \sum_{j=1}^{4} C_{ij}\omega_j \tag{2}$$

Where

C_{ij}, the normalization value of scheme i and factor j (i ≤ 3， j ≤ 4)

X_{1j}, the actual value of scheme 1 and factor j

X_{ij}, the actual value of scheme i and factor j

R_i, the sustainability evaluation index of scheme i

ω_j, the weight coefficient of factor j

Figure 5. The hierarchy structure of each scheme

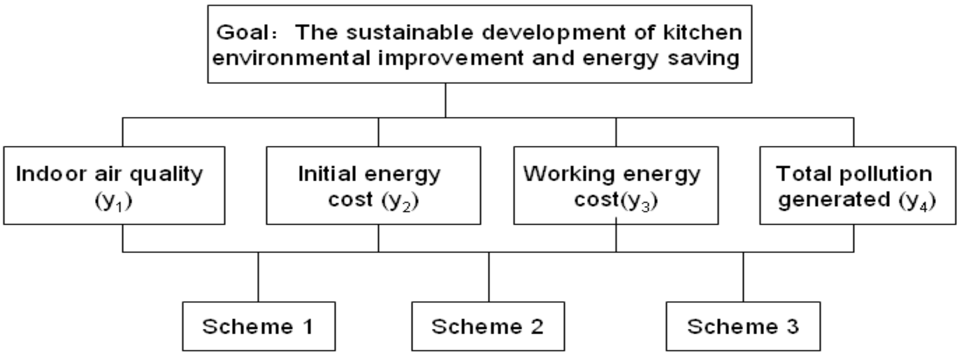


Table 4. The weight coefficients of the factors

Factor	y_1	y_2	y_3	y_4
Weight coefficient	0.125	0.125	0.375	0.375

Table 5. The calculated values of Cij

Factor / Scheme	y_1	y_2	y_3	y_4
1	1	1	1	1
2	1.144	0.952	1	1
3	2.383	0.857	0.75	1

4. Conclusions

1. The locations of contaminants' accumulation are high near to ceiling above the location of cook utensil (range) in vertical planes, and close to the walls in horizontal planes in a residential kitchen in conventional ventilation mode.

2. When the multiple exergy intensity is adopted as an evaluation index of indoor air quality, the scheme 3 (installed a range-hood, a natural air make-up system, and a full exhaust system) is the best one for indoor air quality, the next is the scheme 2 (installed a range-hood and a natural air make-up system), and the conventional ventilation mode.

3. After the sustainability of every scheme is studied by using Analytical Hierarchy Process, the scheme 3 (installed a range-hood, a natural air make-up system, and a full exhaust system) is the best one for the sustainability, the next is the scheme 2 (installed a range-hood and a natural air make-up system), and the conventional ventilation mode.

4. It improves the air quality in kitchen effectively and conforms to the sustainable development strategies when the scheme 3 (installed a range-hood, a natural air make-up system, and a full exhaust system) is proposed as an alternative of the conventional ventilation mode.

Conflict of Interest

The authors declare no conflict of interest.

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