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NUMERICAL SIMULATION OF IAQ AND ENERGY NEED BY COMIS MODEL:(OUTCOME FROM IEA ANNEX27: EVALUATION AND DEMONSTRATION OF DEMESTIC VENTILATION SYSTEMS)

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Synopsis

The purpose of this research is to give an overall prospect of the performance of 4 kinds of ventilation systems for dwellings using numerical simulation under various conditions. The total number of combinations of various parameters for the calculation is 174.
Calculations for pollutant concentration, humidity and condensation, interior pressure and airflow rate, heat energy by ventiulation,etc. are performed hourly through the heating season.
In this paper, a new method was described to evaluate the effect of ventilation system under climatic conditions for each type of dwelling with an airtightness level from the points of view of indoor air quality and energy need. In addition, by means of statistical method, the impact of various parameters on IAQ and ventilaton systems was discussed.

1. Introduction

It's well known that most people spend most of their time within buildings. So ventilation of buildings is very important people to not only obtain acceptable indoor air quality but also avoid mould growth and condensation. On the other hand, the increase of ventilation rates may lead to exceeding energy consumption. Because evaluation of the performance of ventilation systems is directly linked to many design/control parameters, so it's very hard to get exact results up to now. Subtask 2 of IEA ANNEX27 'Evaluation and Demonstration of Domestic Ventilation Systems' has a purpose of statistical analysis using numerical simulation for airflow, indoor air pollution and energy load. In this paper, COMIS multi-zone infiltration and pollutant transport model was used for this research work, which had been developed by IEA ANNEX23 'Multi-zone Airflow Modelling'[1].

2. Assumption

2.1 Model house

A single-family house(D4c) and 4-story multi-family house(D4a) was chosen to represent different dwelling types. Room height was 2.5m and the living room always faced south. Their floor plans are shown in Fig 1. Leakages for 1, 2.5, 5.0[1/h@50Pa] were assumed to be concentrated in two parts on each exterior wall, one half located at 0.625m and the other half at 1.875m above the floor. For the 10[ach@50Pa] the additional cracks were located at the floor and ceiling. The standard family form and living schedule are based on European statistics[2]. Indoor air temperature was uniformly at 20℃. Except for the door between kitchen and hall, all the others were considered closed. Four main ventilation systems, i.e., natural, natural passive stack, mechanical exhaust and mechanical central supply and exhaust (represented as system 1 to 4 respectively in this paper). Installation of local fans in bathroom (weekdays: 6:00 - 8:00, weekends: 9:00 - 11:00) and/or kitchen (17:00 - 18:00) and supply air openings in habitable rooms was combined with ventilation system. The wind pressure values[3] are subject to different wind directions. Three regions were selected to represent the different climate conditions. Table 1 illustrates their main meteorologic parameters. Window airing was assumed at bedrooms only and the duration was 4h(8:00 - 12:00)

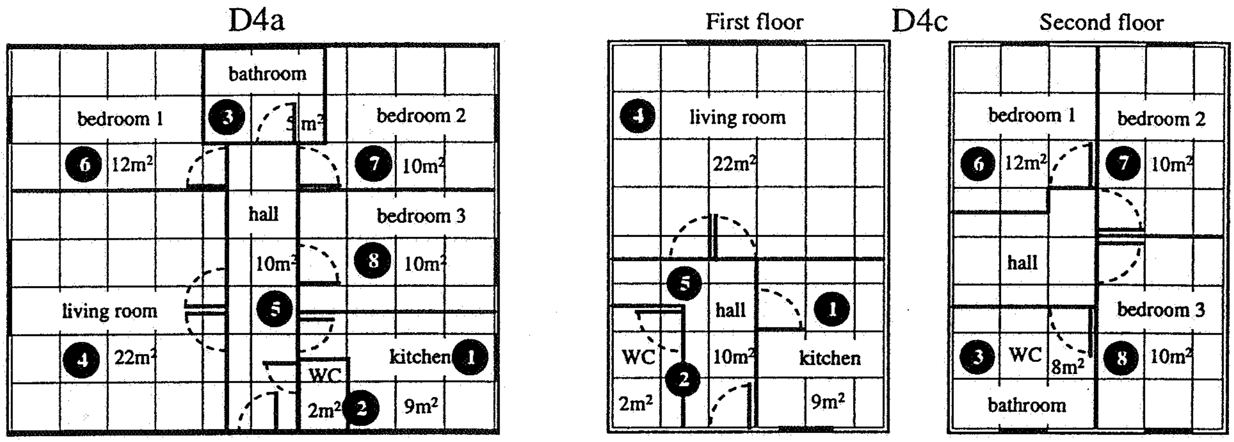

Fig. 1: Floor plan of dwelling example

Table 1: Climate characteristic of three regions

Climate	Cold (Ottawa)	Moderate (London)	Mild (Nice)
Heating Season	2 Oct-20 May	24 Sep-20 May	13 Nov-27 Apr
Average temperature [℃]	1.44	7.51	10.1
Average humidity [g/kg']	2.97	5.22	5.31
Average wind speed [m/s]	4.44	1.97	4.34
Prevailing wind direction	186.8° (S)	182.1° (S)	264.9° (SW)

during weekdays.

2.2 Indoor air pollutants

Except humidity, four kinds of air pollutants were simulated to reflect IAQ. They are described as the following: the pollutant generated from rooms themselves(Plt1), it is based on a constant emission related to the room area(1g/m²h); CO_2(Plt2); the pollutanat which is related to cooking activities(Plt3), it is considered to be proportional to the water production during cooking ($1g_{Plt3}=2g_{vapor}$); the pollutant which is related to passive smoking(Plt4), the emission source is set up as 20g/h for one smoker[3]. The metabolic CO_2 and water vapor (including showering and cooking) production of spacious case(2 persons) is given in Fig 2. The outdoor concentration of all pollutants was neglected. Since some kinds of indoor air pollutants' concentration is always low relatively, so a special index was introduced in terms of CV to show the cumulative effect of pollutant on occupancy during heating season[4]. It's the cumulated value for each occupancy on the basis of the number of exposured hours Nh above a certain indoor air pollutant concentration Ci: Nh(Ci). If 700ppm is defined as a threshold value of CO_2 for human's heath,

$$CV_{CO2(700)} = \int Nh(Ci) \quad \text{for } Ci>700ppm \qquad (1)$$

2.3 Combination of all the simulation parameters

As mentioned above, the related parameters for sensitivity studies are summarized in Table 2. A selection of critical combinations, at least 174, has been made on mathematical statistics.

3. Calculation example

3.1 Indoor air pollutant concentration variation

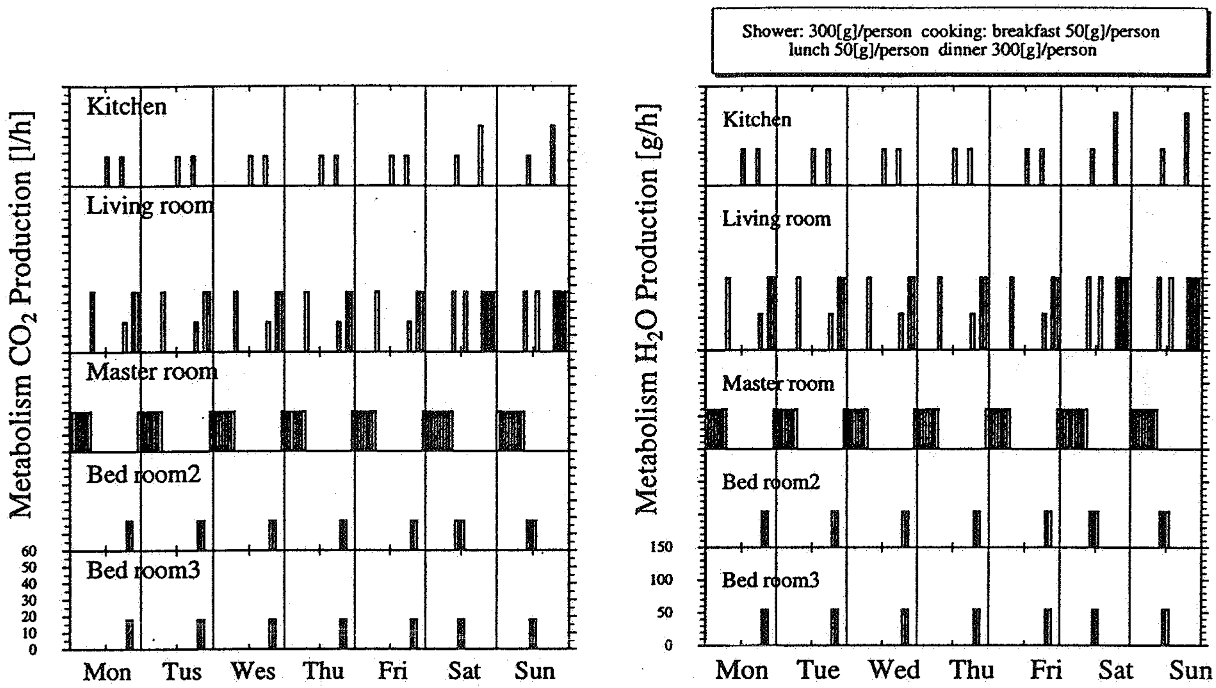

Fig. 2: Metabolic CO_2 and water vapor generation schedule

Table 2: Entire parameters for simulation

Parameter	Level		
Dwelling type	Single family house	Ground floor in 4 story multi-family house	Top floor in 4 story multi-family house
Leakage	10(5)	5(2.5)	2.5(1)
Occupancy	5(Crowded)	4(Average)	2(Spacious)
Window Airing	climate depending	50% climate depending	Closed
Climate	Cold (Ottawa)	Moderate (London)	Mild (Nice)
Supply Area (system 2,3) *(system 1)*	400cm^2 410cm^2	100cm^2 101cm^2	0cm^2
Flow Rate (system 3,4)	45 *l/s*	30 *l/s*	15 *l/s*
Local Fan Kitchen	ON(100 *l/s*)		OFF
Local Fan Bath	ON(25 *l/s*)		OFF
Comments	( ) for system 4		

Table 3 describes two examples coded as N17 and N105. The former is system 1 while the latter is system 3. Fig 3 shows the indoor air pollutant concentration variation in the living room and the total fresh airflow rate during a certain week period(1 Jan～7 Jan). It can be found that owing to window airing and local fan, the variation in air flow rate becomes substantial. Especially when windows are opened, the fresh air rate increases up to 271[m^3/h] and can be more than 10 times the rate when closed and the consequencial effects on the indoor environment are obvious. The highest pollutants' level occurres in the living room between 6:00p.m. and 12:00p.m.. The CO_2 concentration during this period even exceedes 1.0g/kg'.

3.2 Airflow distribution

Table 3: Detailed description of N105 and N17

Case No.	Dwelling type	Leakage [1/h@50Pa]	Occupancy [persons]	Window airing	Climate	Supply area [cm2]	Flow rate [l/s]	Local fan kitchen [l/s]	Local fan bathroom [l/s]
N105	D4c	2.5.	2	open	Nice	400	15	100	25
N17	D4c	2.5	2	closed	Nice	410	no	no	no

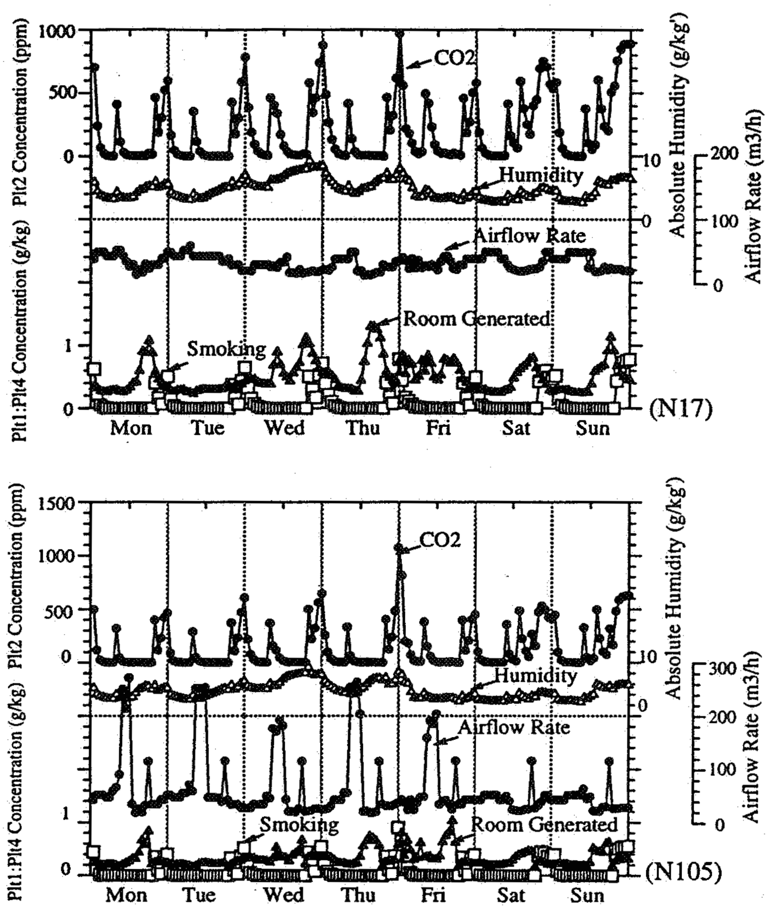

Fig. 3: Variation of pollutant concentration and airflow rate (N17 and N105)

From Fig 4 to Fig 7 two special times were selected to study the impact of window airing and kitchen hood on instantaneous airflow through all the zones for N17 and N105. The selected time and the instantaneous meteorological data are shown in Table 4. The figures show that due to mechanical sytem and local fan, airflow rates through habitable rooms increase to a great exent, especially when window airing is used at the same time. For example, at 9:00a.m., the airflow through bedroom 1,2 for system 3 is 6.26, 5.52 times as much as that for system 1. At 17:00p.m., the airflow through living room for system 1 is only 21.8[m^3/h], while for system 3 it increases up to 123.6[m^3/h] and the total flow pattern of this dwelling changes completely.

Table 4: Description of the two selected time

Date/Time	Wind speed [m/s]	Wind direction [°]	Outdoor temperature [°C]
07Nov / 9:00a.m.	5	0 (N)	14
12Nov / 5:00p.m.	3	270 (NW)	11.6

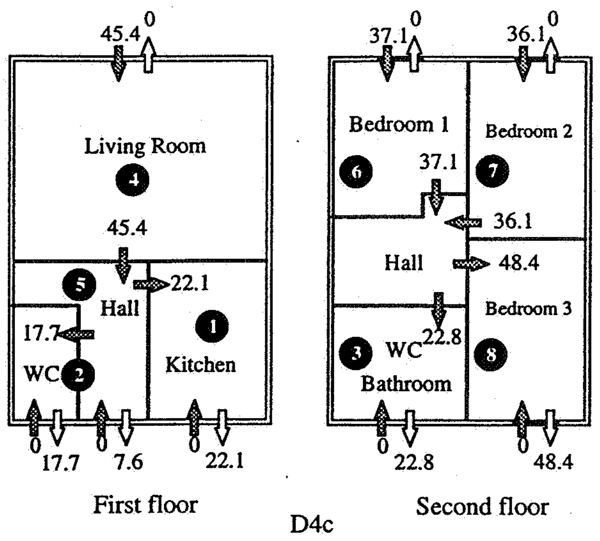

Fig. 4: Distribution of airflow rates at 9:00a.m.(N17)

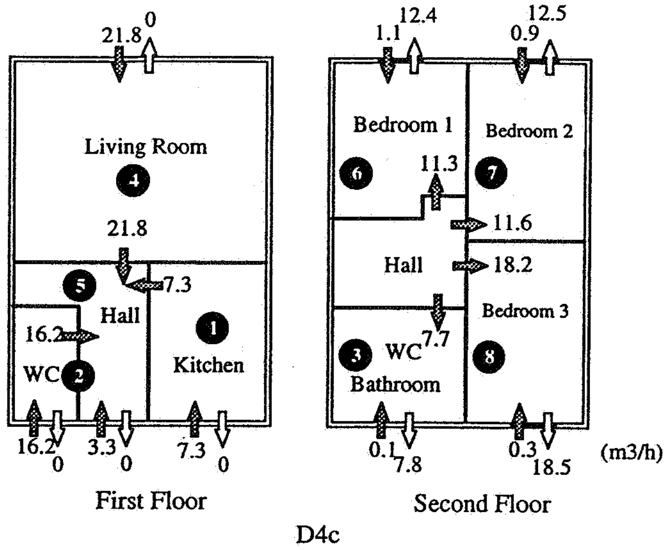

Fig. 5: Distribution of airflow rates at 5:00p.m.(N17)

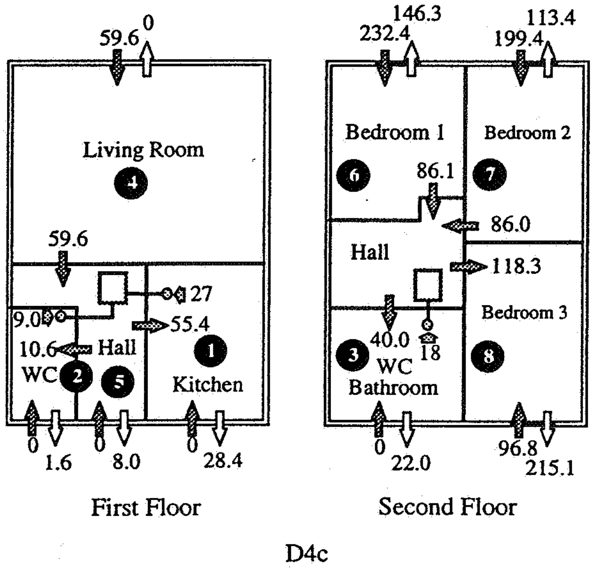

Fig. 6: Distribution of airflow rates at 9:00a.m.(N105)

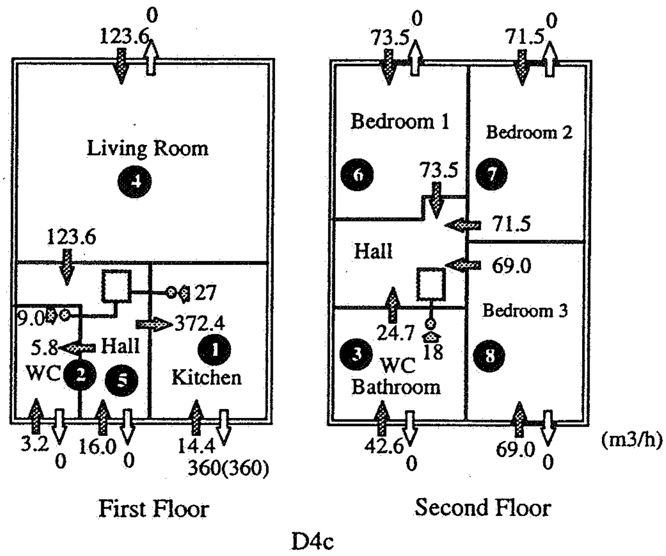

Fig. 7: Distribution of airflow rates at 5:00p.m.(N105)

4. Analysis of calculation result

4.1 Evaluation of ventilation system

Because the total energy consumption(due to both air exchange and fan's electrical need) during heating season and CO_2 concentration (represented by $CV_{CO2(700)}$ here) are the most important evaluation indexes associated with indoor environment, the combination of them will be an effective method to evaluate the synthetical performance of the ventilation system. Fig. 8 shows that $CV_{CO2(700)}$ of all the 174 cases is mainly in a range of 0 to 4000[g/kg × h] while the energy consumption within a range of 0 to 15000[kWh]. As an essential trend, the higher energy consumption results in lower $CV_{CO2(700)}$. Taking acceptable CO_2 level and energy conservation into account, limit values at 300[g/kg × h]and 3000[kWh] were derived to represent their threshold values respectively. The limit values were obtained from the average level of all the 174 cases. A rectangle is enclosed as shown in Fig 8 using the two limit values. Within this region, both CO_2

level and energy consumption are lower than the average level of total cases, thus this region can be considered as an 'Acceptable Region' for occupancy. Then an 'Acceptable Ratio' was derived based on the ratio of the case number of each ventilation system in the 'Acceptable Region' to the total case number of that system respectively. As shown in Table 5, when other parameters are assumed the same, the 'Acceptable Ratio' of system 4 is the highest. Apparently, using system 4, the CO_2 level and energy consumption are the most acceptable for occupancy. It can be attributed to the fact that indoor air quality and air distribution are good due to the force of central mechanism, and energy consumption is less than other systems because of heat recovery.

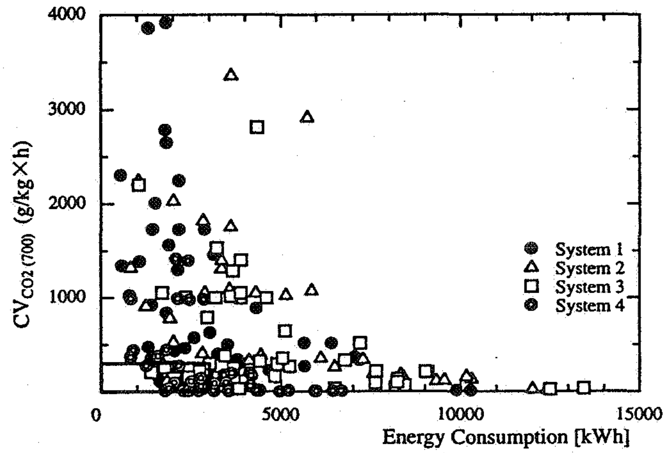

Fig. 8: Impact of different ventilation systems on energy and IAQ

Table 5: 'Acceptable Ratio' for various systems

System	1	2	3	4
Acceptable Ratio	0.14	0.16	0.16	0.33

4.2 Evaluation of related parameters

4.2.1 Predictable formulae

As indicated in Table 2, the related parameters and their corresponding categories are all represented by qualitative data. According to multivariate statistical theory, quantification I analysis method is available to analyze the relationship between these parameters and $CV_{CO2(700)}$. The calcuation results are summaried in Table 6. From this table, the predictable formula of every ventilation system for $CV_{CO2(700)}$ can be obtained. Equction 2 shows the predictable formula of natural ventilation system(system 1)as an example:

$$CV_{CO2(700)} = 997.3-118.34x_{11}+194.77x_{12}+204.7x_{13}-585.61x_{21}+118.7x_{22}+522.75x_{23}+274.62x_{31}-23.6x_{32}-262.08x_{33}-20.4x_{41}+11.2x_{42}+14.54x_{43}-77.92x_{51}+661.5x_{52}-277.34x_{53}-596.8x_{61}+80.8x_{62}+554.14x_{63}-27.99x_{81}+16.6x_{82}+11.21x_{91}-6.7x_{92} \quad (2)$$

Using these predictable formulae, the practical extent of indoor CO_2 level can be approximately expected upon any combinations of aforementional parameters. Because the adjusted R squared values in Table 6 are close to 1, these predictable formulae can be regarded to be valid for

Table 6: Category scores of ventilation systems

Item / Category		System 1 R'=0.775 α<0.01	System 2 R'=0.735 α=0.03	System 3 R'=0.707 α=0.1	System 4 R'=0.860 α<0.01
Dwelling type	*D4c (x11)*	-118.34	-86.44	-39.3	51.92
	D4agf (x12)	194.7	25.86	1.11	-113.85
	D4atf (x13)	204.7	265.86	16.36	-61.36
	range	323.04	352.3	55.66	165.77
Leakage area '/' for system 4 (n50)	*10/5 (x21)*	-585.61	-432.69	-311.78	-140.36
	5/2.5 (x22)	118.7	-0.01	152.2	61.49
	2.5/1 (x23)	522.75	433.13	213.34	107.81
	range	1108.36	865.82	525.12	248.17
Family number	*5 (x31)*	274.62	312.53	272	231.96
	4 (x32)	-23.6	-253.2	-328.73	59.91
	2 (x33)	-262.08	-178.47	-59.3	-263.68
	range	536.7	491	600.73	495.64
Window airing	*open (x41)*	-20.4	-27.01	79.49	-5.54
	half open (x42)	11.2	40.14	-157.59	61.49
	closed (x43)	14.54	5.75	22.49	-27.02
	range	34.94	67.15	237.08	88.51
Climate	*cold (x51)*	-77.92	-117.19	-101.95	41.88
	moderate (x52)	661.5	527.61	412.85	101.03
	warm (x53)	-277.34	-162.13	-163.19	-95.36
	range	938.84	689.74	576.04	196.39
Supply area '/' for system 1 (cm2)	*400/410 (x61)*	-596.8	-527.51	-260.62	
	100/101 (x62)	80.8	188	-9.88	
	0 (x63)	554.14	427.97	267.02	
	range	1150.94	955.48	527.64	
Mechanical flow rate (l/s)	*45 (x71)*			-303.51	-380.18
	30 (x72)			164.65	-445.88
	15 (x73)			196.97	560.88
	range			500.48	1006.76
Kitchen fan	*on (x81)*	-27.99	-14.88	80.01	-18.61
	off (x82)	16.6	8.82	-44.15	11.03
	range	44.59	23.7	124.16	29.64
Bathroom fan	*on (x91)*	11.21	16.75	-212.4	-8.26
	off (x92)	-6.7	-9.93	117.19	4.89
	range	17.91	26.68	329.59	13.15
Constant		997.3	705.86	518.76	255.26

application.

4.2.2 Evaluation from category scores

The category score in Table 6 can show how the variation of indoor CO_2 level changes from the average level. The following are the evaluation results:

1) $CV_{CO2(700)}$ is higher in multi-family house(D4a) than single-family house;

2) $CV_{CO2(700)}$ decreases with the increase of leakage or area of supple air, decrease of family number, operation of local fans and opening of windows.

3) $CV_{CO2(700)}$ in moderate weather condition seems the worst among the three weather conditions. In practice, the reason is perhaps due to $CV_{CO2(700)}$ depends on the number of exposured hours strongly and the heating season of London is much longer than Nice and Ottawa.

4.2.3 Evaluation of item range

According to quantification I analysis method, the item range in Table 6 can be used to show which parameter influences on indoor CO_2 level significantly and which one slightly. The following can be concluded:

1) System1: the impact of leakage, area of supply air and weather condition on $CV_{CO2(700)}$ looks far more greater than other parameters;

2) System2: the impact of leakage and area of supply air on $CV_{CO2(700)}$ looks a little greater than other parameters;

3) System3: the impact of leakage, area of supply air, weather condition, family number and mechanical air flow rate on $CV_{CO2(700)}$ looks roughly equal;

4) System4: mechanical air flow rate is the dominant parameter affecting $CV_{CO2(700)}$ among all the parameters;

5) The impact of window airing and local fan on $CV_{CO2(700)}$ looks week for every system.

5. Conclusions

In accordance with results from the 'Acceptable Ratio' proposed in this paper, mechanical central supply and exhaust system has been confirmed to lead to lower indoor CO_2 level and reduce energy consumption. On the base of quantification I analysis statistical method, the impact of related parameters with every system on $CV_{CO2(700)}$ respectively was studied quantitatively. Controlling these parameters appropriately can guarantee an adequate indoor air enveironment for occupancy.

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