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ASSESSMENT OF KITCHEN VENTILATION SYSTEM WITH SUPPLY AIR AND EXHAUST DEVICES

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We are studying on the mechanical ventilation system with supply air and exhaust devices in kitchen which is arranged in the core of house, to provide the ventilation rate at minimum level and maintain the indoor pollutant concentration caused at cooking under the permission level, in the neighborhood living room.

In this paper, we tried to find out first the influence of kitchen ventilation system on the indoor air pollution and cooking load in living space through the theoretical model. It is shown that the implement of such ventilation system have much effectiveness. Secondly, we examined the performance of ventilation system in an examined the performance of ventilation system in an exciting kitchen through measuring of ventilation rate by tracer gas method. It is found that the supply air in let on the upper part of the entrance door have usefulness in respect of ventilation.

REFERENCES

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INTRODUCTION

Recently there is a tendency that the Japanese apartment houses in urban area are getting more high rise and compact due to the rocketing land price and the concentration of population. As a result,to let their exterior look fancy ,the part of the utility area,such as kitchen,bathroom and toilet is arranged in the core of house. The living rooms and bed rooms are facing outside. In such designed house,turning on the hood fan often induce the drastic fall of the indoor air pressure. This lets the polluted air from bathroom and toilet flow back to other rooms,and sometimes causes trouble at opening or closing the entrance door. And it leads the heat load in living room to increase. There have been happened some another kinds of troubles. Therefore,not being infiltrated outdoor air through the opening gaps,but the important thing is to establish some ventilation system which can discharge the polluted air effectively by installing the outdoor air inlet.

We are working on supply air system which can control the ventilation rate at minimum level and maintain the indoor concentration of pollutants generated from gas stove at cooking under the permission level.

In this paper we tried to find out first the influences on the indoor pollutant concentration and the cooling load when the supply air and exhaust system is adopted in kitchen. Secondly we examined the performance of the supply air and exhaust system in an existing kitchen by measuring the ventilation rate by means of tracer gas method.

THEORETICAL EXAMINATION

1.Ventilation model of residential house

The performance of the supply air and exhaust system in kitchen was examined from both viewpoints of the pollutant concentration and the cooling load caused by cooking on gas stove,through the ventilation model shown by Fig.1 and Fig.2. On this occasion,we assumed the relationship between the local exhaust rate and the exhaust leakage rate from the rang hood to be what is shown in Fig.3.

As for the cooling load,the heat transfer through walls and the heat flux from occupants were excluded from targets for this examination.

And the air and the pollutant coming in each area were assumed to have completely mixed within the area.

2.Calculation of the indoor pollutant concentration and the cooling load from cooking

The indoor pollutant concentration and the cooling load from cooking for various conditions of exhaust rate and supply air rate,can be obtained by substituting the conditions above into Eq.(1) and (2).

The calculated result in the case without the air inlet(at k=0) is shown in Fig.4. The solid line(1) in the figure shows the case without the local exhaust appliance. The solid line(2) shows the case without the stagnant air area in living room (at $A=\infty$),while the hood fan is working effectively. The solid line(3) shows the case with the stagnant air area in living room (at A=0),while the hood fan is working effectively.

It is considered that the case with the actual life condition is somewhere between the line(2) and (3).

So it is evident from Fig.4 that the indoor air quality are able to be maintained in good state when the local exhaust in kitchen is operated and when the stagnant air area is formed in living room.

Next,Fig.5 shows the indoor pollutant concentration and the cooling load from cooking at the case of $A=\infty$ with outdoor air inlet to kitchen. Fig.6 shows them at the case of A=0 with air inlet.

It is found from Fig.5 and 6 that the indoor air quality become good and also the cooling load becomes smaller when the local supply air rate makes larger. The other way around with the extremely large exhaust rate,the heat load in living room becomes large. Therefore,it is found that there is likely to be an appropriate exhaust rate from the viewpoints of indoor air pollution and energy conservation.

It is found from the result above that the ventilation system with supply air and exhaust devices in kitchen will be effective for both case of the indoor air pollution and heat load from the polluted plume generated by cooking in kitchen.

EXPERIMENTAL EXAMINATION

As mentioned above,this ventilation system is very useful for both the indoor air environment and the energy conservation. Whereas against our supposition sometimes some sorts of side effect occur,such as reducing the exhaust capture capacity of range hood due to disturbance in buoyant plume above gas stove caused by arranging the outdoor air outlet near gas stove,or increasing the indoor pollutant concentration due to making the indoor air scramble with outdoor air which flowed into through the air inlet,and the flowing the polluted stagnant air below the ceiling into a living area. It must be hard a lot to resolve practicably the above problems on the implementation of outdoor air outlet.

This time,we examined the performance of the supply air and exhaust system with the outdoor air inlet on the upper part of entrance door by measuring the ventilation rate.

1. Experimented house
    1)The house locates in the central row on 14F of 15F apartment house. Fig.7 shows the plan of this house and the location of the devices for ventilation.
2. Measured items
    1)Ventilation rate, 2)Exhaust rate of hood fan, 3)Wind direction and velocity on the rooftop, 4)Indoor and outdoor air temperature
3. Experimental method
    1)Measurement of ventilation rate: We used the decay method of tracer gas by using CO_2. We carried out the measurement of ventilation rate on the cases of single room ventilation and coupled rooms ventilation which is flow back and forth mutually between living room and dining-kitchen room.
    2)Exhaust rate of hood fan: We obtained the exhaust rate according to CO_2 concentration at the exhaust outlet by releasing a certain amount of CO_2 in the hood. And also we supposed the exhaust rate from the air velocity at the center of hood,by means knowing previously their relation from measuring simultaneously.
4. Experimental results: Table-1 shows the ventilation rate under various conditions of ventilation system and wind conditions during the experiment.
5. Evaluation of ventilation rate
    1)Ventilation rate of living room and dining-kitchen room under natural ventilation: From Table-1,living room has maintained rather air tightness and is likely to be lake of ventilation. But it will be able to be given enough ventilation with a small window for ventilation,and it will make the number of air change of about 2.0(1/h).
    2)Exhaust rate of hood fan: Figure 8 shows the relationship between the exhaust rate of hood fan and the air velocity at the center of hood.

    The exhaust rate changes by opening and shutting the air inlet in the entrance.

    It indicates that the exhaust rate become lager 5% at minimum operation of hood fan, 1% at minimum and 10% at maximum by opening the air inlet.
    3)Ventilation rate in passage: Figure 5 shows the relationship between the exhaust rate of hood fan and the ventilation rate in passage. When the air inlet is closed,around 70% of the exhaust rate flows from passage into kitchen. Whereas,when the air inlet is opened,it become about 80%.

    This shows that the ventilation performance of air inlet at the entrance is good because implementing the air inlet decreased somewhat the ventilation rate in living room.

4)Ventilation rate in living room: From Table-1,it is found that the ventilation rate in living room become extremely lager when hood fan is operated at maximum power. When the food fan is operated,the total ventilation rate in living room and dining-kitchen room is larger than the exhaust rate of hood.

This may be due to mutual ventilation between coupled rooms-living room and dining-kitchen room.

Q_{lo} which computed for coupled room model,is estimated to be very small from Table-1. From Q_{id}>Q_{di},it is supposed that the outdoor air which flowed into living room,flowed directly into dining-kitchen room. Supposing the infiltration of outdoor air is small,the flow rate into dining-kitchen room is considered to be the total amount of Q_{oi} and the ventilation rate in passage. But Q_{od} is smaller than this total amount. It is supposed that the air flow from passage be unable to mix perfectly the air in dining-kitchen room and short circuit to the exhaust hood.

As a result,we considered that the outdoor air inlet in the entrance have effectiveness in respect of ventilation.

CONCLUSION

1.Application of the supply air and exhaust system is much effective from both view point of indoor air pollution and heat conservation in principle.

2.The outdoor air inlet at the upper part of the entrance door in an existing house may be useful because it makes the ventilation rate in living room decrease.

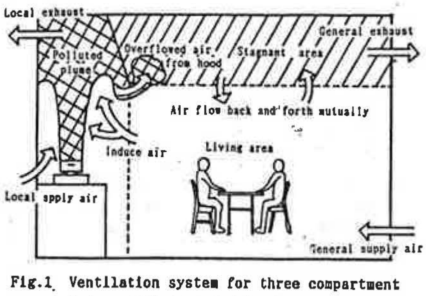
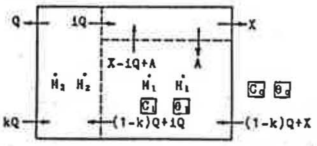


Fig.1 Ventilation system for three compartment indoor pollution model

Q:Local exhaust rate $[m^3/h]$
k:the rate of local supply air to total supply air into kitchen
l:the rate of overflow rate to living room to total exhaust from kitchen
M:the pollutant emission in each area
C:the pollutant concentration in each area
X:the general exhaust rate
A:the incoming air rate from stagnat area to living area
H:Heat emission in each area
θ:Air temperature in each area

Calculated condition
•Cooking condition setting two pan poured water on 2 burner gas stove at maximum operation (heat emission rate,H=186x10²kJ/h CO_2emission rate, M=0.52m³/h)
•Controled indoor air temperature :θ_r=25
•Outdoor air temperature :θ_o=32
•Number of occupants :4 persons
•General exhaust rate :120m³/h

1) lQ≤X



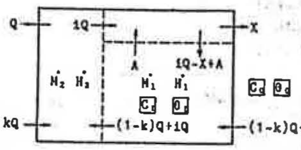
Pollutant concentration in living room

$$C_l = C_o + \frac{M_1 + \frac{1}{1+l}\cdot\frac{A}{X+A}\cdot M_2}{X+(1-k)Q+\frac{1}{1+l}\cdot\frac{A}{X+A}\cdot kQ}$$

Cooling load

$$TL_s = H_1 + \frac{1}{1+l}\cdot\frac{A}{X+A}\cdot H_2 + c\gamma\cdot(\theta_o-\theta_l)\cdot\{X+(1-k)Q+\frac{1}{1+l}\cdot\frac{A}{X+A}\cdot kQ\}$$

2) X≤lQ



Pollutant concentration in living room

$$C_l = C_o + \frac{M_1 + \frac{1}{1+l}\cdot\frac{lQ-X+A}{lQ+A}\cdot M_2}{X+(1-k)Q+\frac{1}{1+l}\cdot\frac{lQ-X+A}{lQ+A}\cdot kQ}$$

Cooling load

$$TL_s = H_1 + \frac{1}{1+l}\cdot\frac{lQ-X+A}{lQ+A}\cdot H_2 + c\gamma\cdot(\theta_o-\theta_l)\cdot\{X+(1-k)Q+\frac{1}{1+l}\cdot\frac{lQ-X+A}{lQ+A}\cdot kQ\}$$

Fig.2 The calculated expressions of pollutant concentration and cooling load in living room showed Fig.1

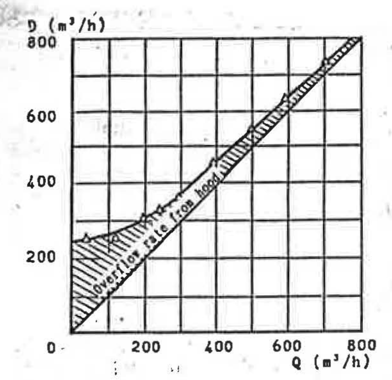


Fig.3 The relationship between local exhaust from hood, Q and air flow of polluted buoyant plume, D at 0.8m height above to two burner

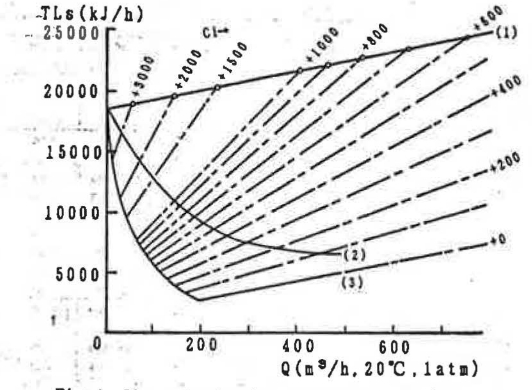


Fig.4 The relationship between local exhaust, Q or general ventilation rate X and cooling load TLs or indoor CO_2 concentration, Ci at A=0 and A=∞

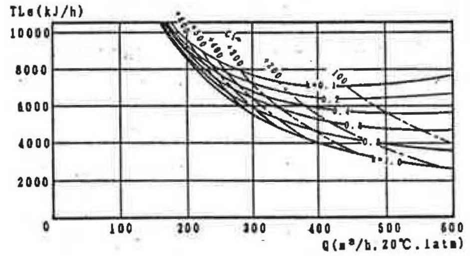


Fig.5 The relationship between local exhaust, Q and cooling load TLs or indoor CO_2 concentration Ci at A=∞

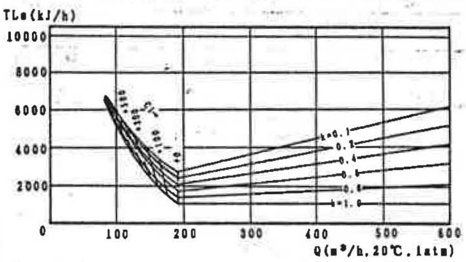


Fig.6 The relationship between local exhaust, Q and cooling load TLs or indoor CO_2 concentration Ci at A=0

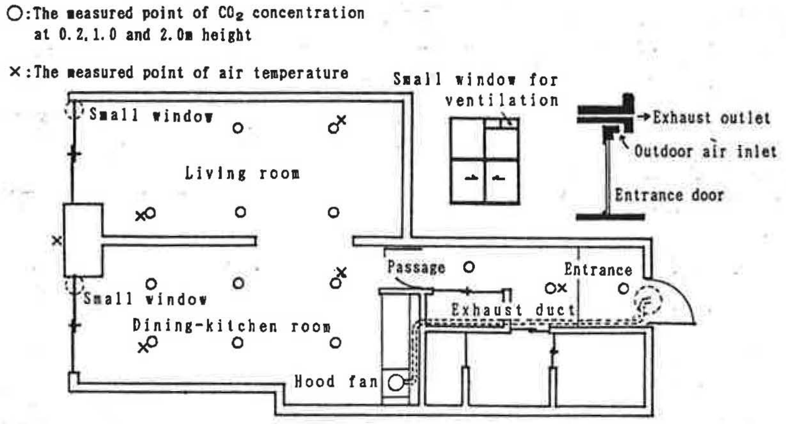


Fig.7 The plan of the experimented house and the location of installation for ventilation

Table 1.1 Ventilation for single room model

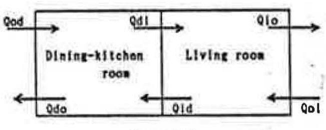
Room	Wind condition		Experimental state			Rate of Air change [1/h]	Ventilation rate[m³/h]
	Direction	Velocity [m/s]	Hood fan	Outdoor air inlet	mixing fan		
Living room and Dining-kitchen room	ENE	4.5	off	close	off	0.3	22
	—	—	off	close	off	2.2	18
Passage	WSW	6.3	minimum	open	off	8.5	108
	—	—	minimum	open	off	8.9	112
	—	—	minimum	open	on	8.4	106
	—	—	minimum	close	off	7.3	92
	NE	3.5	medium	open	off	15.0	189
	SW	4.3	medium	open	off	12.3	155
	SSW	4.9	medium	open	off	12.6	159
	SW	4.0	medium	open	on	13.2	166
	—	—	medium	close	off	10.8	137
	N	2.0	maximum	open	off	24.5	309
	—	—	maximum	open	off	25.5	322
	—	—	maximum	open	off	26.1	329
	—	—	maximum	open	on	25.0	315
	—	—	maximum	close	off	19.2	242
	—	—	maximum	close	off	19.2	242
	—	—	maximum	close	on	18.5	233
Living room	NNE	4.0	medium	open	off	2.4	88
	N	2.2	maximum	open	off	3.5	128

Table 1.2 Exhaust rate of hood fan

Window condition		Exprimental state			Exhaust rate [m³/h]
Direction	Velocity [m/s]	Hood fan	Outdoor air inlet	Passage door	
NNE	3.6	minimum	open	close	135
N	4.5	minimum	open	close	135
NNW	2.4	minimum	open	close	135
N	3.8	medium	open	close	229
N	4.0	medium	open	close	223
NNW	2.7	medium	open	close	223
NNE	4.2	maximum	open	close	381
NNW	3.2	maximum	open	close	399
NNW	3.2	maximum	open	close	402
NNE	3.7	minimum	close	close	129
N	5.1	minimum	close	close	128
N	5.4	minimum	close	close	127
N	3.6	medium	close	close	209
N	5.1	medium	close	close	205
N	5.8	medium	close	close	205
NNE	4.5	maximum	close	close	353
N	4.4	maximum	close	close	360
N	5.2	maximum	close	close	358
NNE	3.9	minimum	close	open	128
N	4.8	minimum	close	open	125
NE	3.5	medium	close	open	204
NNE	5.0	medium	close	open	201
NNE	4.0	maximum	close	open	352
NNE	4.6	maximum	close	open	352

Table 1.3 Air flow rate for coupled room model

Wind condition		Experiemental state		Air flow rate[m³/h]				
direction	velocity	Hood fan	mixing fan	Q_{od}	Q_{dl}	Q_{ld}	Q_{lo}	Q_{ol}
— —	— —	minimum	off	183	80	159	263	22
— —	— —	medium	off	212	118	82	175	51
SSW WSW	2.5 3.8	maximum	off	229	328	233	222	53
SSW SWS	4.0 3.5	minimum	on	120	71	103	148	21
SSW SSW	2.5 2.8	maximum	on	494	349	89	235	43



Air flow circuit for coupled room

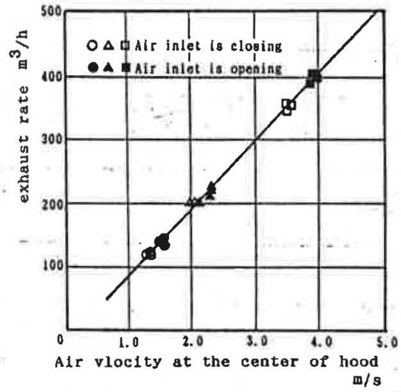


Fig.8 The relationship between air velocity,V at the center of hood and exhaust rate,Q

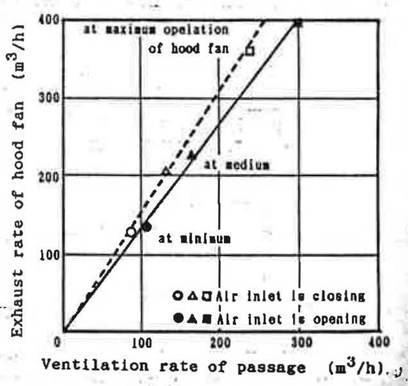


Fig.9 Exhaust rate of hood fan and ventilation rate of passage