Field measurement of carbonyl compound and particles in South Korea residential spaces

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ABSTRACT

In Korea, a large amount of fine dust and carbonyl compounds is generated during cooking in the kitchen. The purpose of this study is to select 20 apartment houses and measure contaminants that are generated during cooking in apartment houses in Korea. The measurement result showed that 15 out of 20 apartment houses exceeded the guidelines for PM10 based on its peak concentration. The concentration of carbonyl compounds was measured in the descending order of acrolein (270.0 ㎍/m^3), formaldehyde (239.5 ㎍/m^3) based on its average concentration. Acrolein and formaldehyde is harmful to the human body because time required for concentration to decrease by below guidelines is too long. The concentration of contaminants increased after cooking in most apartment houses even though there was a ventilation mechanism, and formaldehyde exceeded its standard concentration in 9 apartment houses. As a result of measuring various contaminants comprehensively, it can be determined that ventilation for cooking is insufficient to remove contaminants.

KEYWORDS

- Cooking emission, Range hood, Carbonyl compounds, Kitchen ventilation, Formaldehyde, Acrolein

1 INTRODUCTION

Awareness about indoor air quality and contaminants has increased in Korea based on previous experiences such as the so called sick building syndrome issue. For this reason, ventilation standards for detached houses and apartment houses have been established and the clean health housing construction standards of South Korea were put in place through the Indoor Air Quality Act(2003; 2009; 2013). The Ministry of the Environment of South Korea operates an ‘eco label’ for new apartment buildings as a part of source control measures in order to regulate contaminants such as particles, VOCs (Volatile Organic Compounds) and HCHO (Formaldehyde) emitted from building materials(Shim and Choi, 2017). Also, a study to solve the so called sick building syndrome by improving the indoor air quality of new apartment buildings in Korea was carried out in the past (Choi et al., 2009; Kim et al., 2008).

Although the indoor air quality problem is under control, the issue of contaminants generated indoors due to cooking in the kitchen has come to the fore in recent times. In general, contaminants generated during cooking in the kitchen are removed through the operation of a range hood. However, studies regarding the standards of range hoods such as their capture efficiency are still in progress internationally (AIVC, 2016).

In comparison to previous problems, the source control for cooking in the kitchen is practically difficult and large amounts of contaminants are generated during cooking (Cheng et al., 2016; Huang et al., 2011; Seaman et al., 2009). Especially, carbonyl compounds are known to be major contaminants (sources in cooking fume emissions) that are generated during cooking in the kitchen based on studies over many years (Wang et al., 2017). The concentration of carbonyl compounds increases significantly during cooking, and carbonyl compounds including acrolein have a long half-life of over 10hr (Seaman et al., 2009). Therefore, if the indoor ventilation is low, indoor occupants may be exposed to a high concentration of carbonyl compounds for a long period of time, posing a significantly harmful influence to human health. For this reason, efforts are being made to clearly define HCHO as a representative substance and limit its standard concentration to 210 ㎍/㎥ in order to control the indoor concentration of carbonyl compounds in apartment houses in Korea. At present, the standard concentration of particles is 100~200 ㎍/㎥.

Therefore, the effects of cooking actions on the indoor air quality in apartment houses were evaluated in this study by measuring and analyzing contaminants generated during cooking in the kitchen inside apartment buildings in Korea.

Apartment buildings in Korea consist of mostly of reinforced concrete structures and the design entails that the living room and the kitchen are separated. Also, apartment buildings in Korea are concentrated mostly in downtown areas, so the outdoors concentration of contaminants has a significant effect on indoor space. In addition, when cooking is carried out in the kitchen, the concentration of indoor contaminants increases significantly. Therefore, the concentrations of indoors and outdoors contaminants as well as indoor contaminants before, during and after cooking were measured separately in this study.

2 SITE AND TEST CONDITIONS

2.1 Apartment buildings in Korea

Table 1: Summary of building information

Building no.	Floor areas, m^2	Type of fuels	Type of ventilation	Type of cooking
B1	61	L	H+N.V	F
B2	59	L	H+N.V	F
B3	116	L	H	F
B4	74	L	H+N.V	F
B5	167	E	H	B
B6	48	L	N.V	B
B7	109	L	N.V	F
B8	72	L	N.V	F
B9	59	L	N.V	F
B10	72	L	H+N.V	F
B11	84	E	H	F
B12	72	L	N.V	F
B13	84	L	-	S
B14	68	L	H	F
B15	157	L	H+N.V	T
B16	74	L	H	B
B17	114	L	N.V	S
B18	106	L	H	B
B19	72	L	N.V	S
B20	108	L	N.V	F

* L: LNG, E: Electricity
H: Hood, H+N.V: Hood + Natural ventilation, N.V: Natural ventilation
B: Broiling, F: Frying, S: Soup, T: Toast

The range hood is installed in most apartment buildings in order to remove contaminants generated during cooking, and LNG and electricity are used as the fuel for cooking. The number of target buildings for measurement was 20 apartment houses, and the measurement was carried out during summer (July) in Korea. The measurement was carried out with indoor temperatures ranging between 25 ℃ and 26 ℃, and the indoor temperature increased by approximately 1~2 ℃ during cooking.

It was determined that the main cooking methods in Korea included boiling and frying, and these two methods were mainly used when the actual field measurement were carried out. No separate restriction was applied to the cooking method or time so that sampling was carried out and analyzed while indoor occupants carried out cooking as usual.

The indoor occupants removed indoor contaminants by operating the range hood or through natural ventilation during cooking except for one target apartment house, and the operation of all range hoods was stopped after cooking.

Among the 20 sampled apartment houses, there was no ventilation in one of the sampled apartment houses, the range hood was operated in 6 apartment houses, natural ventilation was carried out in 7 apartment houses and 6 apartment houses used both natural ventilation and a range hood.

2.2 Field measurement method

The measured contaminants and environmental conditions of the target buildings are shown in Table 2. The ventilation in a building was calculated using the CO_2 tracer gas method(ASTM, 2000), and the average ventilation of the target buildings and the standard deviation were 0.8±0.4 (1/h).

The contaminants were measured at 2 places including the kitchen and the living room at the same time. The background concentration of fine dust was measured for 1 hour before cooking. On the other hand, the carbonyl compounds were sampled (0.2~0.3L/min) at the site for 15 minutes before cooking, for 15 minutes during the cooking period and for 15 minutes after cooking equally using a mini pump, and the sampled carbonyl compounds were analyzed using the liquid chromatograph(LC) method. A total of 6 types of carbonyl compounds (formaldehyde, acetaldehyde, acrolein, Propionaldehyde, butyraldehyde, benzaldehyde) were analyzed using this method.

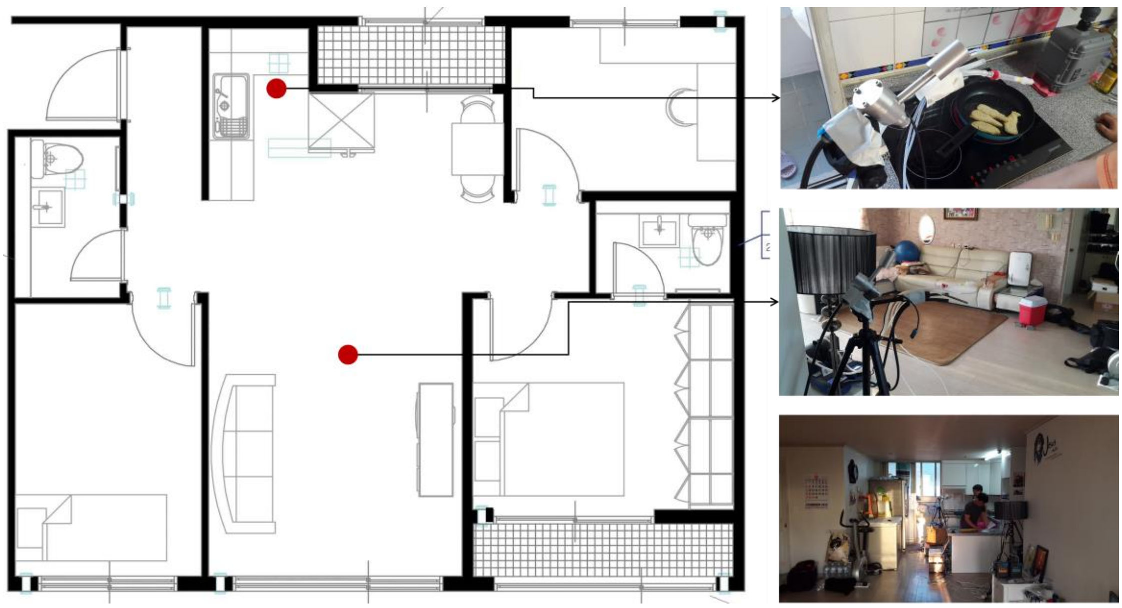

Figure 1: Example of plan & sampled compounds

Table 2: Measuring instrument

Measuring target	Measuring instrument
Air change rate	Photoacoustic multi-gas monitor (INNOVA 1412, Denmark)
Particle Matter	Aerosol monitor (TSI 8532, USA)
Indoor temperature, humidity	Data logger (SATO SK-L200, Japan)
Carbonyl compounds	HPLC-UV method with Mini pump (Walters Alliance HPLC, USA)

3 RESULT

3.1 PM_{10}, PM2.5

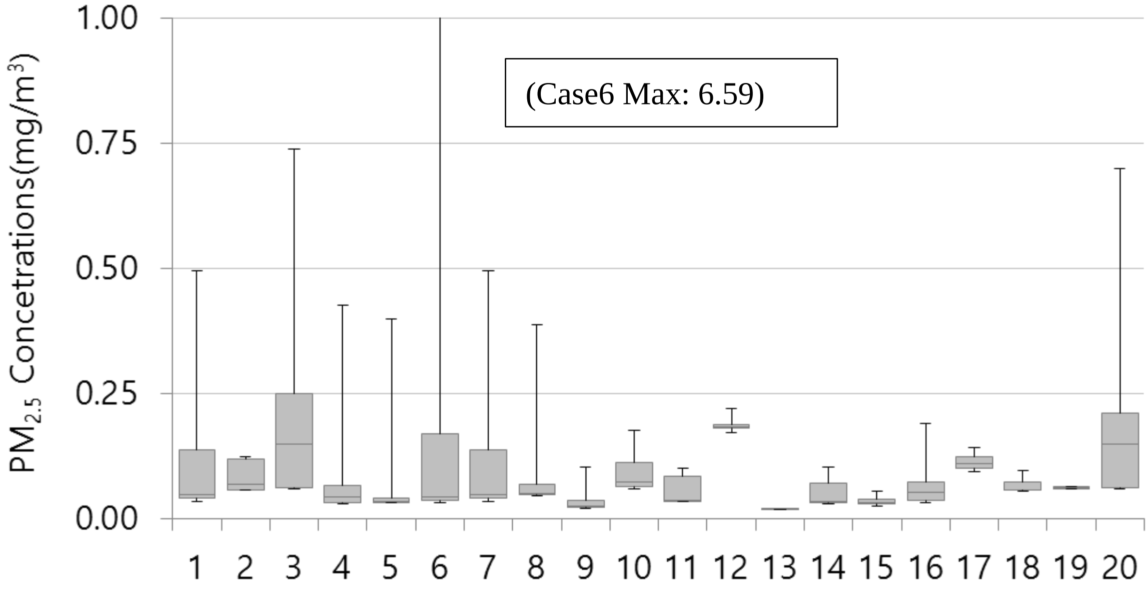

Figure 2: Result of $PM_{2.5}$.in cooking period.

As a result of measuring fine dust in 20 apartment houses, it was confirmed that the concentration of fine dust ($PM_{2.5}$) increased significantly during cooking as shown in Figure 2. While the background concentration in target buildings before cooking was 0.05mg/m^3, the background concentration increased up to 6.59mg/m^3 during cooking. For $PM_{2.5}$, the concentration of fine dust increased during cooking so that the maximum concentration measured was very high (maximum average concentration: 0.70 mg/m^3).

The concentration of $PM_{2.5}$ during the cooking period was as high as 0.10 mg/m^3. Some indoor occupants carried out natural ventilation activities or operated a range hood during cooking, but it was insufficient to remove all contaminants generated during cooking with regard to $PM_{2.5}$.

Similar to $PM_{2.5}$, the concentration of PM_{10} also increased significantly. The average concentration in the 20 houses during cooking periods was 0.70 mg/m^3, and 7 houses exceeded the standard concentration during cooking and 15 houses exceeded the maximum concentration. It was confirmed through this result that a large amount of fine dust was generated though cooking in the kitchen and that the operation of a range hood and natural ventilation methods that were occasionally utilized during cooking at home were insufficient to remove all of the fine dust.

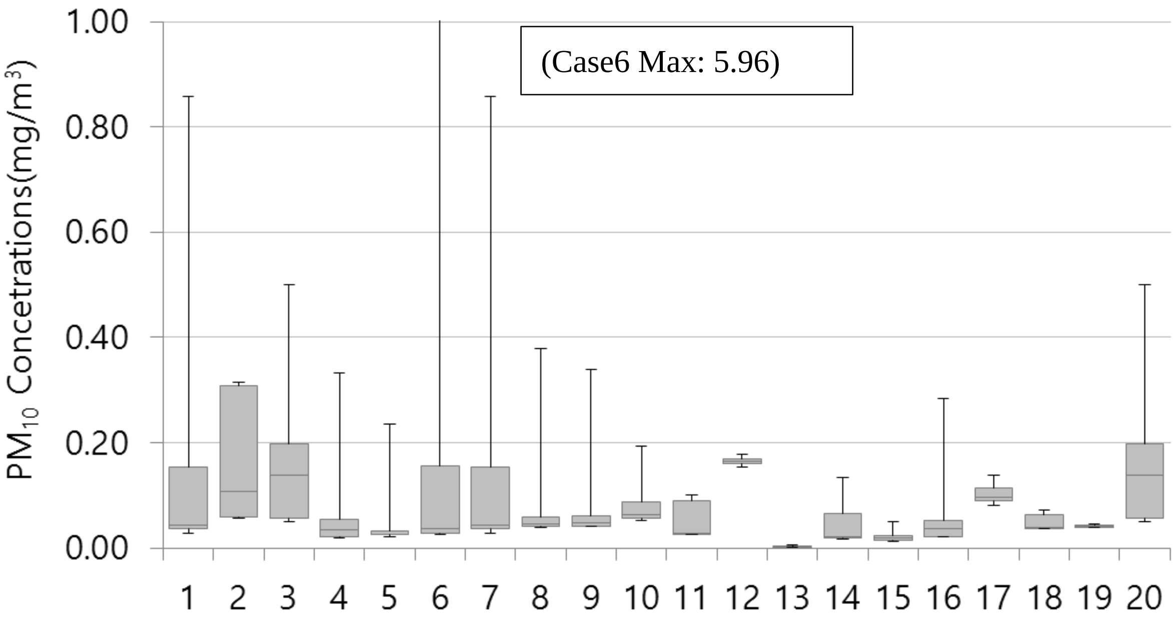

Figure 3: Result of PM_{10}. In cooking and after cooking period.

3.2 Carbonyl compounds

Before measuring the concentration of carbonyl compounds according to cooking action, indoor contaminants were measured. The concentration of formaldehyde in the target buildings (n=20) was 194.4 ㎍/ m^3 on average with its median value being 154.5 ㎍/ m^3 and standard deviation being 121.8 ㎍/ m^3.

Table 3: Background concentration, $C_{background}$ (㎍/m^3, n=20)

	Mean	SD	Min	Max	Med
Formaldehyde	194.4	121.8	78.0	495.0	154.5
Acetaldehyde	85.1	41.1	36.0	210.0	79.5
Acrolein	253.7	112.6	96.0	501.0	210.0
Propionaldehyde	8.6	22.5	0.0	84.0	0.0
Butyraldehyde	120.8	63.9	30.0	234.0	103.5
Benzaldehyde	29.6	4.5	21.0	36.0	30.0

*SD: Standard deviation, Min: Minimum, Max: Maximum, Med: Median, Max: Maximum

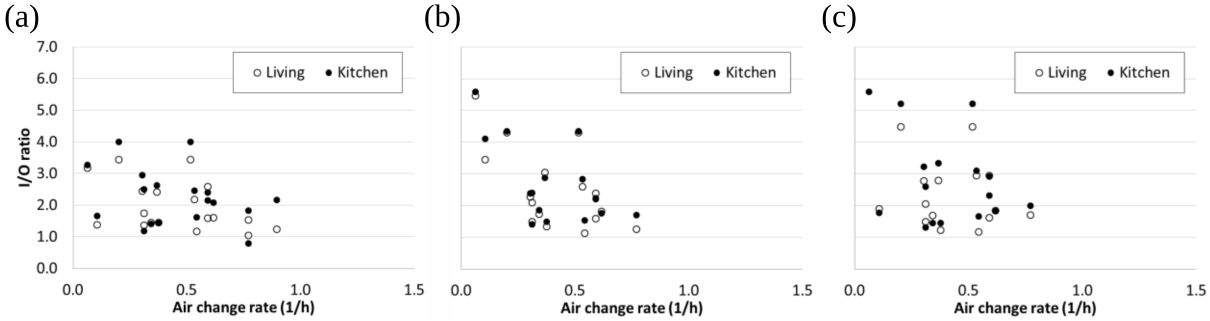

Figure 4: I/O ratios for formaldehyde concentration measured in residential with air change rate.
(a) Data measured before cooking, (b) Data measured for cooking, (c) Data measured after cooking.

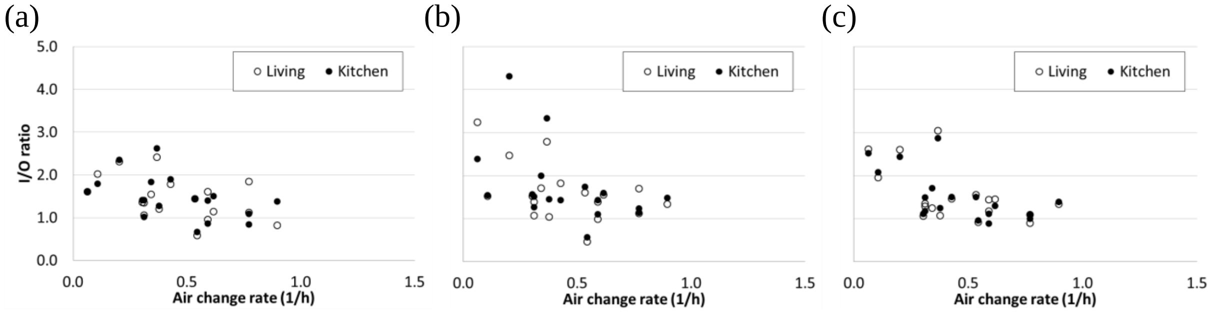

Figure 5: I/O ratios for acrolein concentration measured in residential with air change rate.
(a) Data measured before cooking, (b) Data measured for cooking, (c) Data measured after cooking.

9 apartment houses exceeded 210 ㎍/㎥, which is the formaldehyde standard concentration in apartment houses in Korea. The average concentration of contaminants in the target buildings was measured in the descending order of acrolein (254.0 ㎍/m^3), formaldehyde (160.5 ㎍/ m^3), butyraldehyde (120.0 ㎍/m^3), acetaldehyde (85.9 ㎍/m^3), benzaldehyde (29.7 ㎍/m^3) and propionaldehyde (7.8 ㎍/m^3). The top two substances have a very long half-life and high concentrations of these substances shows that the necessary indoor ventilation is not being carried out properly.

Fig 4, 5 shows the correlation between I/O ratios for formaldehyde, acrolein concentrations and the air change rates. In spite of difference of quantities, similar to concentration of formaldehyde, acrolein also tended to be inversely proportional to ventilation.

The I/O ratios before cooking was 1.4, 2.0 although the ratio during, after cooking was higher than 1.4. This suggests that formaldehyde was significantly increased by cooking activities in Korea despite operating natural, mechanical ventilation. Formaldehyde concentrations in kitchen are more than living room for cooking and after cooking activities.

Table 4: Concentrations of carbonyl compounds entire period with mean and standard deviations (㎍/m^3, n=20)

	Before Living	**Before Kitchen**	**Cooking Living**	**Cooking Kitchen**	**After Living**	**After Kitchen**	**Outdoors condition**
Form-aldehyde	194.4±121.8	219.3±128.3	262.1±245.7	276.5±220.2	231.8±188.0	252.8±193.0	89.1±47.4
Acet-aldehyde	85.1±41.1	84.8±35.4	125.1±78.9	154.8±101.7	115.8±79.1	116.3±665.9	61.1±22.6
Acrolein	253.7±112.6	252.0±123.7	280.8±178.4	301.8±173.0	270.2±152.1	261.8±134.6	184.8±92.2
Propion-aldehyde	8.6±22.5	9.8±23.5	51.5±82.3	80.7±95.4	28.7±39.5	29.1±39.6	3.0±13.4
Butyr-aldehyde	120.8±63.9	120.5±60.6	113.6±59.0	117.6±63.92	100.4±58.3	105.0±50.2	157.4±118.9
Benz-aldehyde	29.6±4.5	29.7±7.0	27.0±10.4	30.3±35.2	26.6±9.8	26.3±10.2	24.3±12.8

Judging from this result, the concentration of these two contaminants is determined by other factors including the cooking methods of indoor occupants and the cooking duration period in addition to ventilation. Table 4 indicates concentrations of carbonyl compounds entire period with mean and standard deviations. Every carbonyl compound concentrations in indoors were higher than outdoor concentration except butyraldehyde. Butyraldehyde, benzaldehyde is not relevant as to the cooking activities. Formaldehyde, acrolein was confirmed that the contaminants generated due to cooking still remained after cooking. Besides ventilation rates, the cause of increase concentrations is various conditions including various cooking types, different cooking behaviors, materials, time by indoor occupant and ventilation efficiency had significant effects.

4 CONCLUSIONS

A ventilator mechanism is installed mandatorily in Korea, and especially ERV (Energy recovery ventilator) is installed in many apartment houses, maintaining indoor air quality. However, the ventilator was not operated in most apartment houses in summer (and also winter) when the measurements were carried out. 15 apartment houses exceeded the Guidelines for PM_{10} based on the maximum concentration and 7 apartment houses exceeded the Guidelines for $PM_{2.5}$ based on the average concentration. The average concentration of $PM_{2.5}$ during cooking period was 0.08 mg/m^3 and the average concentration of PM_{10} was $0.1mg/m^3$.

A very high concentration of most carbonyl compounds was measured during cooking period and the standard concentration of formaldehyde was exceeded in 9 apartment houses. A large amount of acrolein and formaldehyde was generated due to cooking actions, but ventilation in indoor spaces was not carried out properly during and after the cooking, so the high concentration status was maintained indoors for a long period of time after cooking.

The I/O ratio for formaldehyde before cooking was 2,0. The ratio during cooking was 2.7, 2.9. The I/O ratio for formaldehyde before cooking was 1.4. The ratio during cooking was 1.9, 1.7. This suggests that formaldehyde was significantly increased by cooking activities in Korea despite operating natural, mechanical ventilation. Formaldehyde concentrations in kitchen are more than living room for cooking and after cooking activities. Ventilation procedures are not being carried out properly for dilute contaminants and this is particularly so during cooking periods.

In this study, the contaminants generated due to cooking in the kitchen, a topic never studied before in Korea, were measured and the preliminary data regarding indoor air quality was presented. Ventilation is the most important means to prevent deterioration in the indoor air quality. Also, cooking styles and ventilation methods employed by indoor occupants may vary significantly, but generally speaking the ventilation methods employed in apartment houses in Korea are insufficient and so the level of indoor contaminants is high.

5 ACKNOWLEDGEMENTS

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