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Effect of Ventilation Method on Indoor Air Quality when Cooking at Home

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Abstract

Purpose: Indoor air quality is critically affected by cooking processes, with various ingredients and ventilation methods significantly impacting pollutant concentrations. This study investigated particulate matter (PM-10 and PM-2.5) and carbon dioxide levels during cooking under three ventilation scenarios: no ventilation, range hood operation only, and range hood operation with windows open. The experiment used three food types—pork belly, mackerel, and dumplings—prepared on a gas stove. IoT air quality sensors measured pollutant concentrations at specific kitchen and room locations. Results revealed substantial variations in particulate matter increases across different ventilation methods: No ventilation demonstrated the most dramatic pollutant concentration increases, with mackerel showing the highest rise: PM-10 increased 50.9 times, PM-2.5 increased 44 times. Range hood only operation showed moderate pollutant concentration increases, where mackerel again displayed significant rises: PM-10 increased 12.1 times, PM-2.5 increased 9.44 times.

The range hood with windows open approach presented the lowest pollutant concentration increases, representing the least impact on particulate matter levels and proving the most effective ventilation method. The study conclusively demonstrated that simultaneous use of natural and mechanical ventilation is most effective in managing indoor air quality during cooking. By providing empirical evidence of ventilation's impact, the research offers practical guidelines for reducing indoor air pollution generated during routine cooking activities

Keywords : indoor air quality, cooking, ventilation methods, fine dust

JEL Classification Code : F64, Q24, Q56

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1. Introduction

Indoor Air Quality (IAQ) is becoming increasingly important as the time we spend indoors increases. According to the National Institute of Environmental Research, we spend an average of over 21 hours a day indoors, of which more than 14 hours are spent inside our homes. Indoor spaces generate various pollutants not only from external sources but also from activities such as smoking, indoor heating equipment, and cooking processes. During cooking, numerous pollutants are emitted that can linger in the indoor environment, potentially deteriorating air quality. Moreover, when ventilation is insufficient, pollutants generated during home cooking can spread beyond the kitchen to the entire indoor space, causing harm to occupants.

Some studies have reported that oil smoke produced during cooking can be a risk factor for lung cancer. In particular, fine dust is most extensively released during kitchen cooking processes, significantly degrading indoor air quality.

The translation maintains the scientific and informative tone of the original Korean text, highlighting the critical issues surrounding indoor air pollution and its potential health impacts.

Fine dust can be divided into particulate matter (PM-10) with a diameter of 10 micrometers or less and ultrafine dust (PM-2.5) with a diameter of 2.5 micrometers or less. Fine dust is classified as a Class 1 carcinogen by the International Agency for Research on Cancer (IARC), which is under the World Health Organization (WHO).

Fine dust enters the body through the respiratory tract and settles in the lungs, causing respiratory diseases. It triggers inflammatory responses in the bronchi, potentially exacerbating or causing respiratory conditions such as asthma and chronic bronchitis. Additionally, it is a significant risk factor for cardiovascular diseases like myocardial infarction and stroke.

Research on mortality impacts from short-term exposure to fine and ultrafine dust has confirmed that increases in their concentrations are associated with higher risks of overall and cardiovascular excess mortality.

Carbon dioxide is a colorless, tasteless, and odorless gas primarily emitted through human respiration and produced during fuel combustion. It is commonly used as an indicator of indoor air quality or ventilation conditions. When carbon dioxide reaches 4% during respiration, it begins to accumulate in the alveoli, causing symptoms such as respiratory difficulties and headaches.

As such, pollutants generated during cooking can negatively impact human health. Regarding this, Lee Myung-gu et al. (2018) measured the fine dust concentration changes based on cooking ingredients and ventilation methods, confirming that mackerel cooking produces higher fine dust concentrations compared to pork belly, and that fine dust concentrations differ depending on ventilation methods. Kim Hyung-geun et al. (2016) verified that fine dust generated during cooking increases the fine dust concentrations in both the kitchen and living room. Kim Hyun-ju et al. (2020) measured carbon dioxide and fine dust concentration changes during cooking based on ingredients and ventilation methods, and found that operating the ventilation fan during cooking maintains consistent concentrations of carbon dioxide and fine dust.

The concentration of harmful substances varies depending on cooking ingredients and ventilation methods during the cooking process, and the generated harmful substances can spread beyond the kitchen. Therefore, management is necessary to maintain appropriate indoor air quality.

Consequently, this study aims to understand the impact of ventilation methods on indoor air quality by dividing ventilation methods into three types, measuring the concentration of pollutants generated during cooking with different ingredients, and confirming the spread of pollutants by measuring their concentrations in the room as well as the kitchen.

2. Literature Review

2.1. Reasons for selecting measurement factors

Among the harmful substances generated during cooking, fine dust can be classified into particulate matter (PM-10) with particle diameters of 10 micrometers or less and ultrafine dust (PM-2.5) with particle diameters of 2.5 micrometers or less. Fine dust is designated as a Class 1 carcinogen by the International Agency for Research on Cancer (IARC) under the World Health Organization (WHO). It can penetrate the respiratory system into the lungs, accumulate in lung cells, cause inflammation and lung diseases, and adhere to blood vessels, affecting cardiovascular function. Fine dust generated during indoor cooking differs from outdoor fine dust in that its source is very close to the occupants, presenting a higher risk of direct exposure.

Carbon dioxide is a colorless, tasteless, and odorless gas primarily emitted through human respiration and produced during fuel combustion. It is mainly used as an indicator of indoor air quality or ventilation conditions. When carbon dioxide reaches 4% during respiration, it begins to increase within the alveoli, causing symptoms such as respiratory difficulties and headaches.

2.2. Characteristics of the research location

This study was conducted in an apartment. The apartment is 59㎡ in size and located on the second floor. The living room is connected to the kitchen, and the apartment consists of three bedrooms and two bathrooms. To assess the impact of harmful substances generated during cooking on the rooms while minimizing the spread of kitchen air, the measurements were conducted with all doors and windows closed, specifically the doors of two bedrooms (excluding the target room for measurement), the main entrance door, bathroom doors, and balcony windows.

The kitchen and living room are connected, with dimensions of 3.6m wide and 7.935m long. The bedrooms measure 3.3m wide and 2.3m long.

Figure 1: Waterproof and insulated floor plan

2.3. Experimental conditions

In order to find out the effects of harmful substances generated during cooking at home, the breathing zone was set as the measurement point at an actual home, and the reasons for selecting the measurement point are as follows. According to the “2022 Health Checkup Statistics” published by the National Health Insurance Corporation, the average height of women in their 20s to 80s is 158.26 cm. Reflecting this, the measurement location was measured 140 cm from the ground and 20 cm away from the cooking utensil, assuming the breathing zone to be 140 cm based on an adult woman with a body height of 158 cm. When measuring in a room, it was assumed that the person was sitting at a desk, so the average sitting height of women in their 20s to 80s was 82.7 cm. Considering the average sitting Popliteal height of women in their 20s to 80s of 37.34 cm announced by Size Korea, the measurement was made at the center of the room 102 cm from the ground.

The frying pan used as a cooking utensil had a diameter of 28 cm, the weight of the pork belly and mackerel used in the experiment was 120 g (±10 g), the weight of the fried dumplings (frozen food) was unified as 4 pieces (140 g), the cooking oil used for the mackerel was 15 ml, and the fried dumplings (frozen food) were 25 ml. The gas range fuel used was LNG (Liquefied Natural Gas), the heating power was set to level 1.5 out of 3, and the gas generated from the heat source was ignored. The range hood has 3 levels of airflow, and the maximum airflow is 8㎥/min. In this experiment, the maximum airflow was set to level 3, and the hood was turned on before cooking started. The ventilation methods were as follows according to the ventilation manual of the Ministry of Land, Infrastructure and Transport: 1) no ventilation condition, 2) range hood operation condition, and 3) range hood operation and both windows open.

2.4. Experimental method (measurement method)

In this experiment, we aim to find out the concentration trends of harmful substances such as fine dust, ultrafine dust, and carbon dioxide. The measurement method is as shown in Table 1

Table 1: Measurement method

Measurement method				
Cooking Utensils	Ingredient	Cooking	How to cook	After cooking
Gas stove	Pork belly	6 minute Measurement	Flip every minute	10 minute measurement
	Mackerel	10 minute Measurement	Flip every 2 minute	
	Fried dumplings	6 minute Measurement	Flip every minute	

Pork belly and fried dumplings were cooked for 6 minutes, flipped every minute, and mackerel was cooked for 10 minutes, flipped every 2 minutes. All ingredients were measured for 10 minutes after cooking. In order to minimize the influence of the concentration of hazardous substances from the previous experiment before measurement, ventilation was performed for 30 minutes after the end of the experiment. The concentration of fine dust, ultrafine dust, and carbon dioxide generated during cooking was measured using an IoT air quality sensor and measured at 1-minute intervals

3. Results and Discussion

The changes in the concentration of hazardous substances during and after cooking of the ingredients were continuously measured and graphed. Cooking was completed in 6 minutes for pork belly and fried dumplings, and in 10 minutes for mackerel.

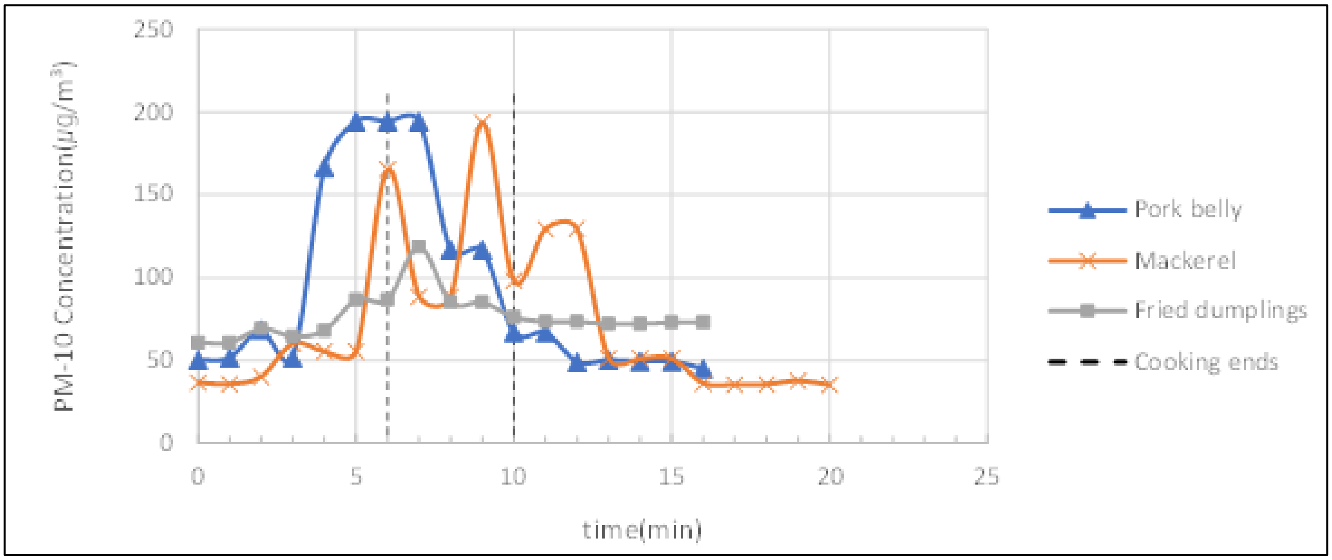

Figure 2: Changes in PM-10 concentration in the kitchen according to natural ventilation and hood operation time

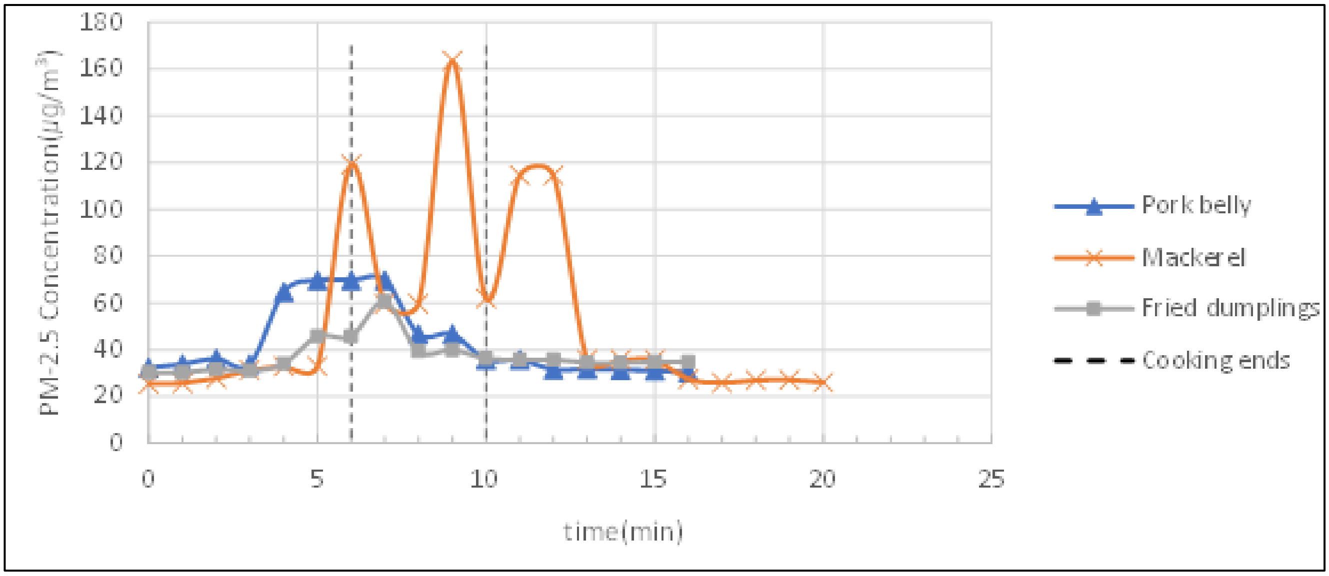

Figure 3: Changes in PM-2.5 concentration in the kitchen according to natural ventilation and hood operation time

Figures 2 and 3 show the trends of PM-10 and PM-2.5 concentrations in the kitchen when natural ventilation and hood use were used simultaneously during cooking on a gas stove.

In the case of pork belly, PM-10 rose to a maximum concentration of 194.3 µg/m³ at the 5-minute mark and maintained a high concentration until the 7th minute (1 minute after cooking ended), after which the concentration began to decrease from the 8th minute, showing a concentration similar to the initial level by the end of the measurement. PM-2.5 also rose to its maximum concentration at the 5-minute mark and began to decrease from the 8th minute, showing a concentration similar to the initial level by the end of the measurement. This appears to be the result of quickly diluting particulate matter concentrations by using natural ventilation and hood simultaneously.

Dumplings and mackerel also showed concentration increases during cooking but maintained temporarily high concentrations before returning to levels similar to the initial concentration.

The PM-10 concentration increased 3.86 times for pork belly, 5.29 times for mackerel, and 1.95 times for dumplings. The PM-2.5 concentration difference was highest for mackerel, with concentrations rising from 25.5 µg/m³ to 163.5 µg/m³, approximately 6.4 times increase. This is about 3 times higher compared to pork belly's 2.16-fold increase and dumplings' 2-fold increase.

Analyzing the final concentration relative to the maximum concentration of particulate matter in the kitchen, the results show: for pork belly, PM-10 and PM-2.5 were 23.16% and 43.55% respectively; for mackerel, 18.22% and 15.96%; for dumplings, 61.58% and 57.52%. On average, PM-10 showed a 34.32% residual rate, and PM-2.5 showed a 39.01% residual rate.

The changes in particulate matter concentrations in the room were minor, with the maximum concentrations compared to initial concentrations showing increases as follows: For PM-10, pork belly, mackerel, and dumplings increased by 1.4 times, 1.3 times, and 1.08 times respectively. For PM-2.5, the increases were 1.2 times, 1.4 times, and 1.07 times for the same foods. Similar to the kitchen, the final concentrations returned to levels similar to the initial concentrations.

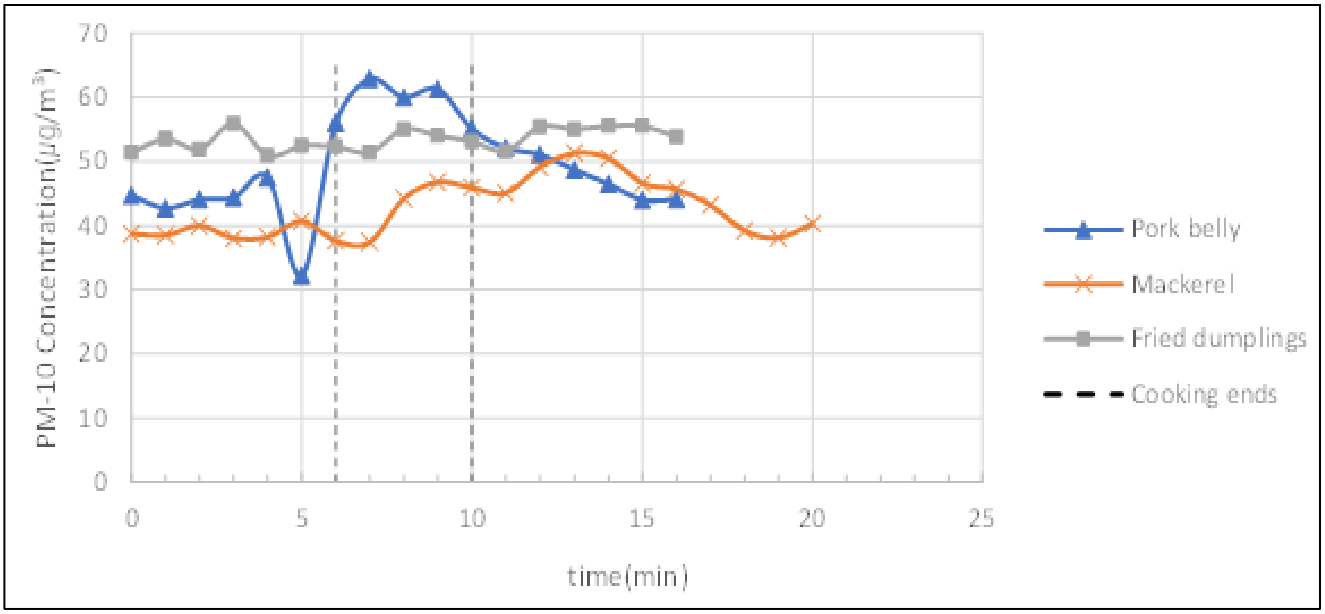

Figure 4: Changes in PM-10 concentration in the rooms according to natural ventilation and hood operation time

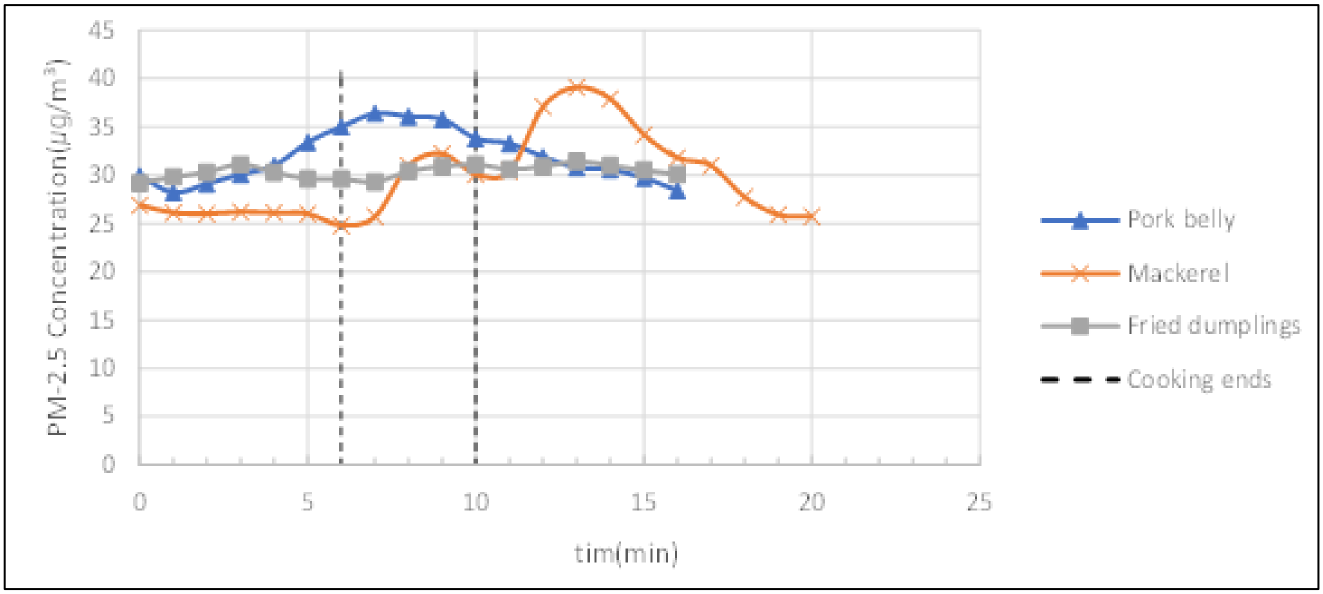

Figure 5: Changes in PM-2.5 concentration in the rooms according to natural ventilation and hood operation time

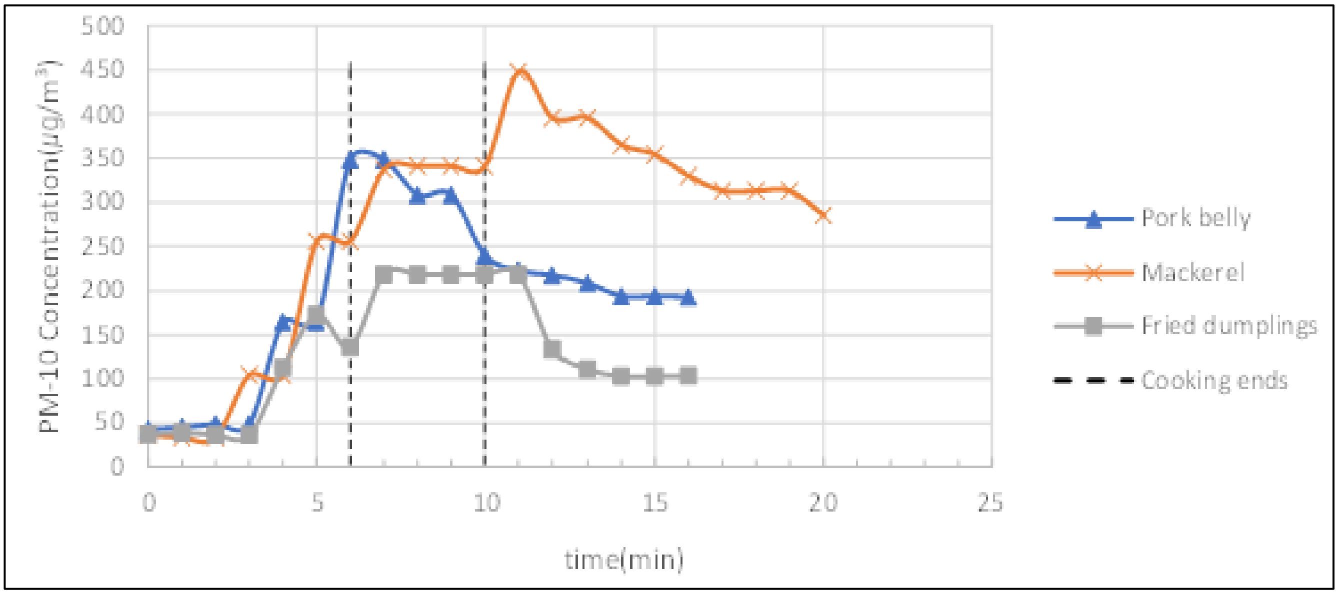

Figure 6: Changes in PM-10 concentration in the kitchen according to hood operation time

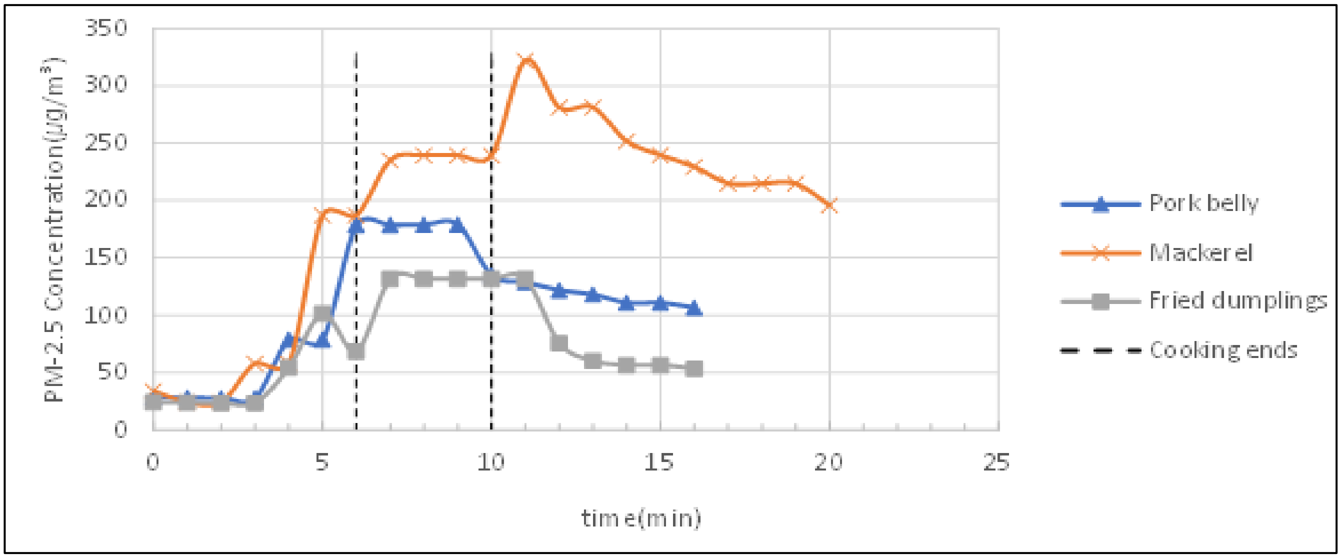

Figure 7: Changes in PM-2.5 concentration in the kitchen according to hood operation time

When using only the hood, without natural ventilation, the particulate matter generation and residual levels were significantly higher. Analyzing the results by ingredient, the particulate matter concentration increase was most pronounced during mackerel cooking. For mackerel, the maximum PM-10 concentration rose to 447.9 μg/m³, which is 12.1 times the initial concentration, while PM-2.5 increased to 322 μg/m³, a 9.4-fold increase. During pork belly cooking, PM-10 increased by 8.1 times and PM-2.5 by 6.3 times. For dumplings, PM-10 and PM-2.5 increased by 5.9 and 5.4 times respectively.

Analysis of the average concentration changes across all ingredients showed that compared to initial concentrations, PM-10 increased by 5.0 times and PM-2.5 by 3.2 times. Additionally, after reaching maximum concentrations, the residual concentration analysis revealed that on average, PM-10 remained at 55.52% of its peak, and PM-2.5 at 53.72% of its maximum level.

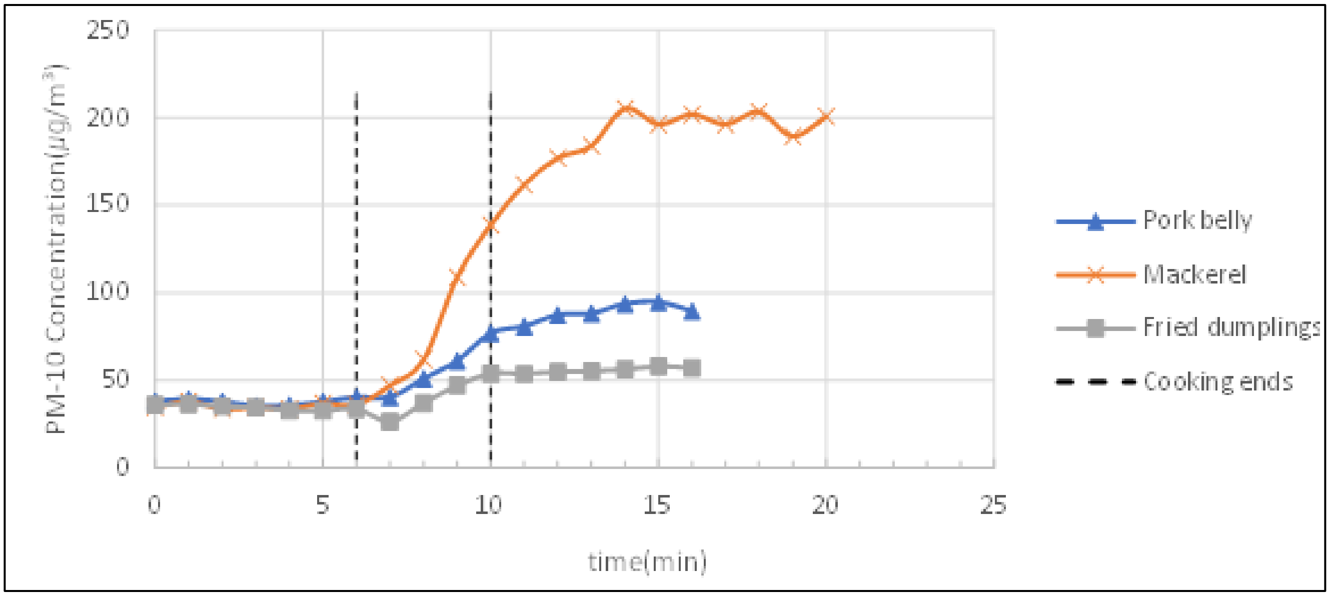

Figure 8: Changes in PM-10 concentration in the room according to hood operation time

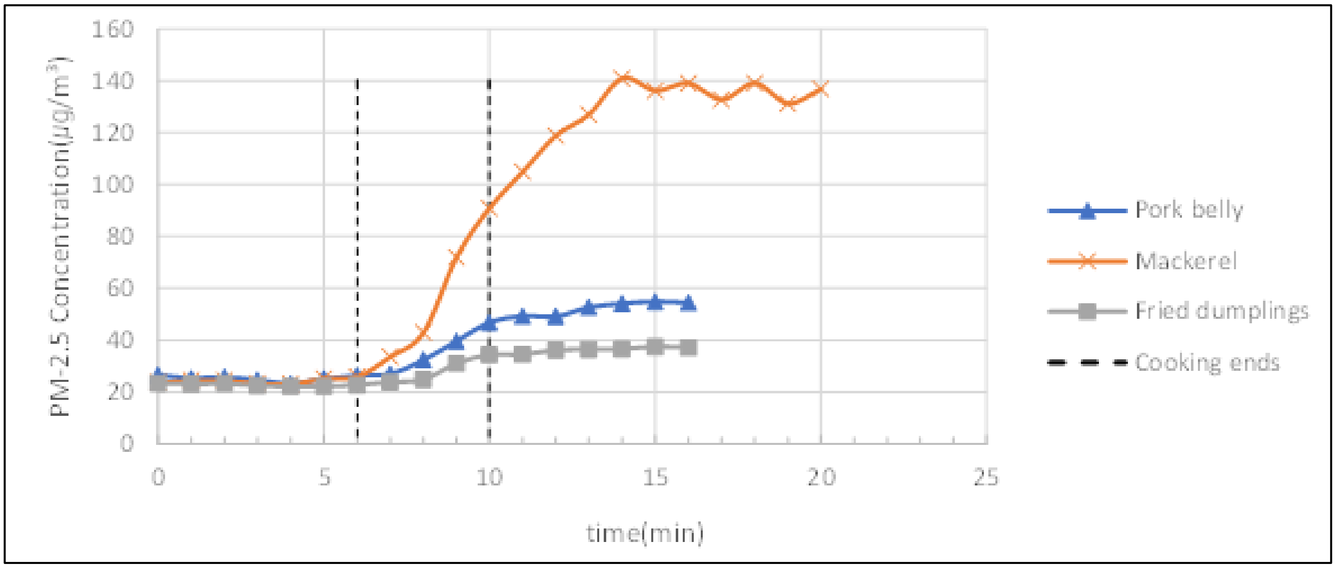

Figure 9: Changes in PM-2.5 concentration in the room according to hood operation time

In the room, mackerel showed the highest increase in particulate matter concentrations, with PM-10 rising 5.9 times and PM-2.5 also increasing 5.9 times. Furthermore, analyzing the final concentration relative to the maximum concentration of particulate matter revealed that on average, PM-10 maintained a 96.79% residual rate, while PM-2.5 showed a 98.46% residual rate. The concentration remained higher compared to the kitchen, which is likely because while the kitchen benefited from hood ventilation, the room did not experience any ventilation effects, thus maintaining high particulate matter concentrations.

In a sealed space without ventilation during cooking, the highest particulate matter generation was observed. The maximum concentrations of PM-10 and PM-2.5 were: pork belly at 749.3 μg/m³ and 216.5 μg/m³ (increases of 24.6 and 10.36 times respectively), mackerel at 1089 μg/m³ and 722.1 μg/m³ (increases of 50.9 and 44 times), and dumplings at 420 μg/m³ and 312.9 μg/m³ (increases of 17.57 and 18.4 times).

In the kitchen, the particulate matter residual rate was the highest among all ingredients. Compared to the maximum concentrations, the final concentrations were: for pork belly, 39.3% and 50.58% for PM-10 and PM-2.5 respectively; for mackerel, 91.68% and 97.22%; and for dumplings, 97.31% and 98.27%. On average, PM-10 showed a 76.1% residual rate, and PM-2.5 showed an 82.02% residual rate.

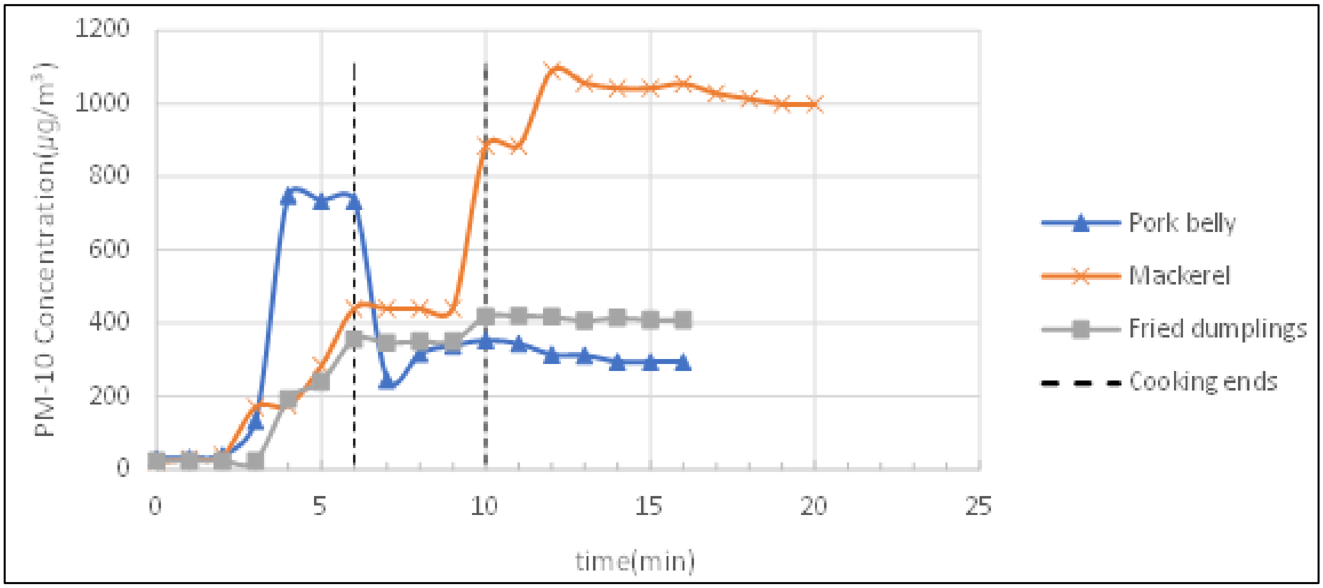

Figure 10: Changes in PM-10 concentrations in kitchen in unventilated confined spaces

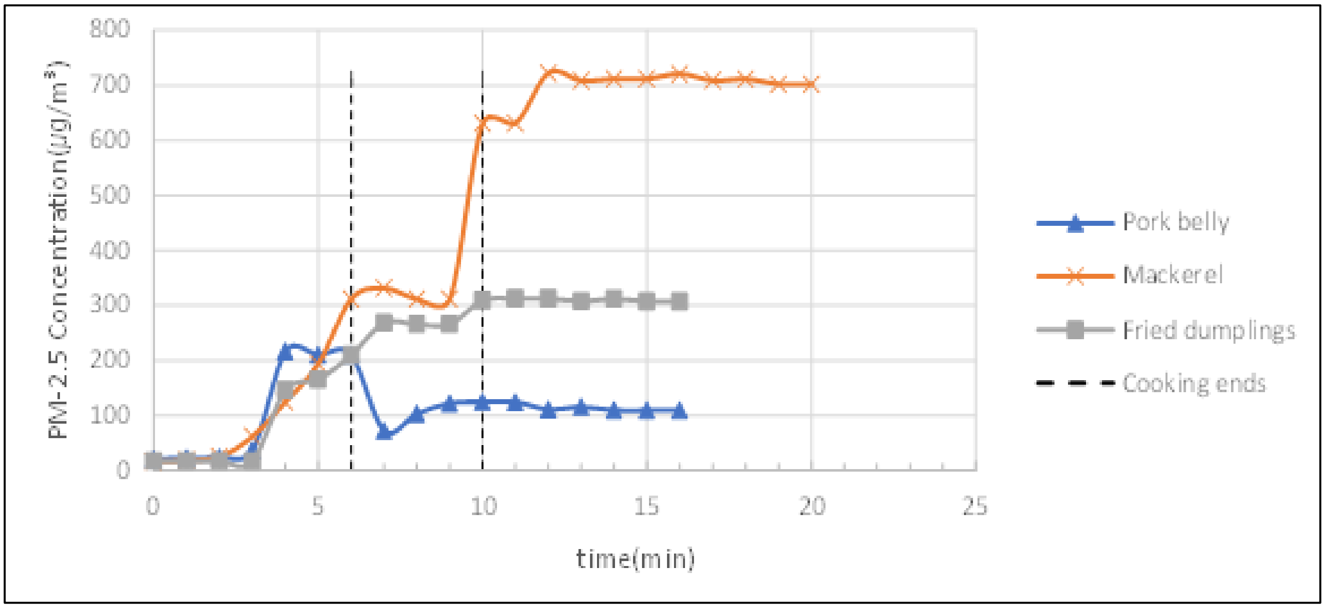

Figure 11: Changes in PM-2.5 concentrations in kitchen in unventilated confined spaces

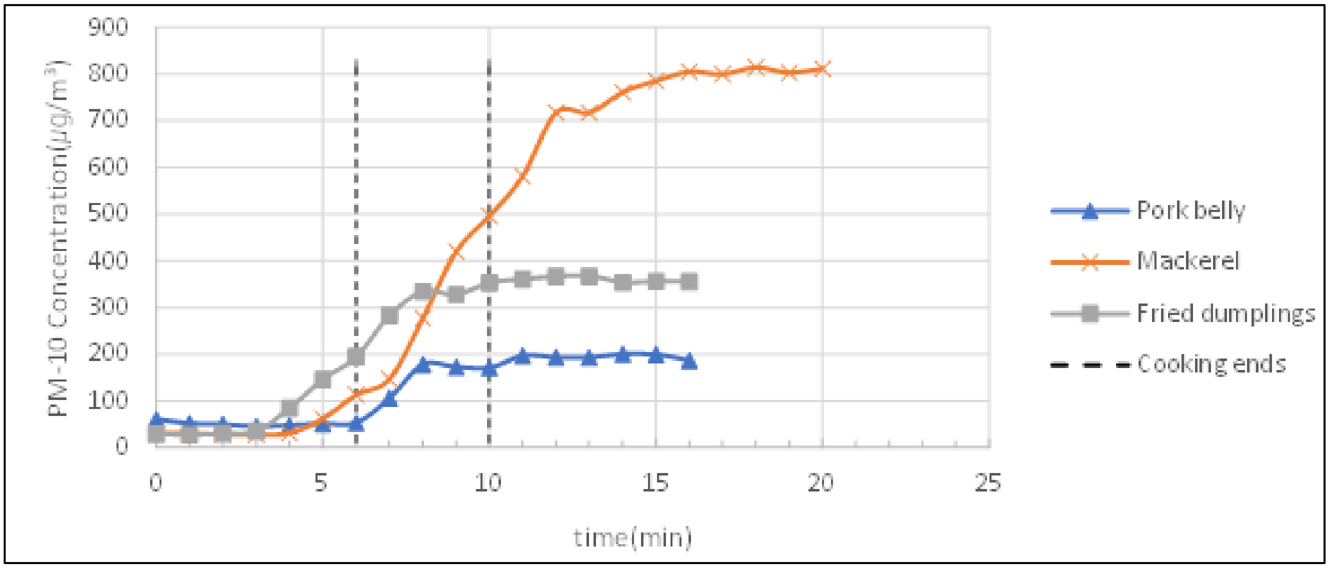

Figure 12: Changes in PM-10 concentrations in room in unventilated confined spaces

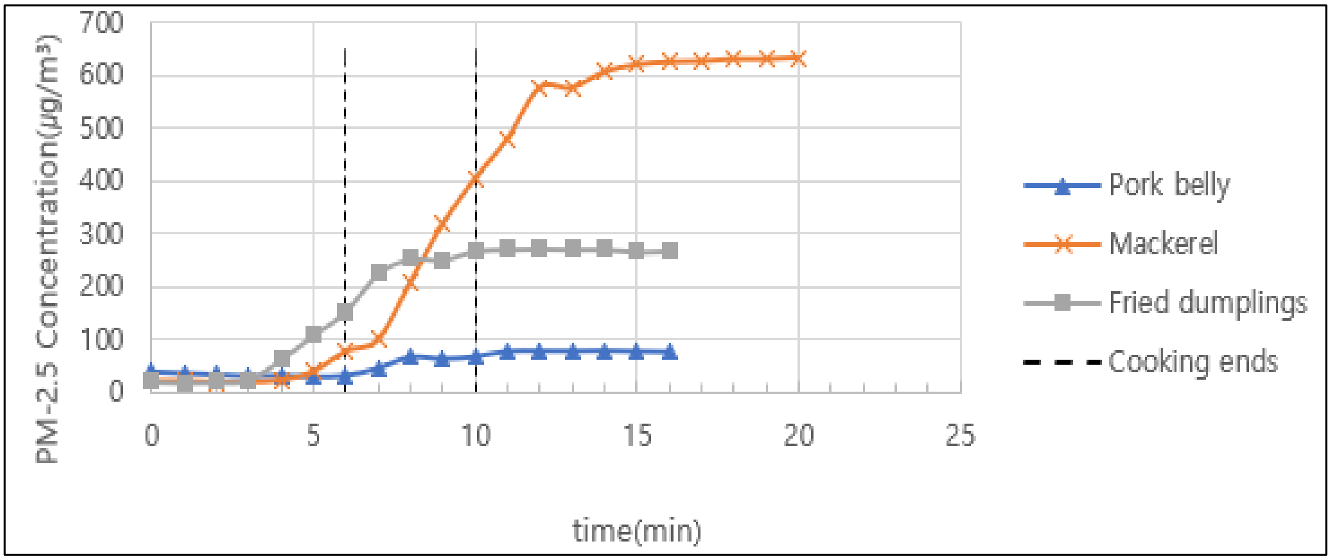

Figure 13: Changes in PM-2.5 concentrations in room in unventilated confined spaces

In the room, particulate matter concentrations were high, similar to the kitchen. The concentrations of PM-10 and PM-2.5 increased as follows: for pork belly, 3.31 times and 2 times respectively; for mackerel, 25.52 times and 29.72 times; and for dumplings, 12.49 times and 13.16 times. The final concentrations compared to the maximum concentrations showed high residual rates of 96.48% for PM-10 and 98.47% for PM-2.5.

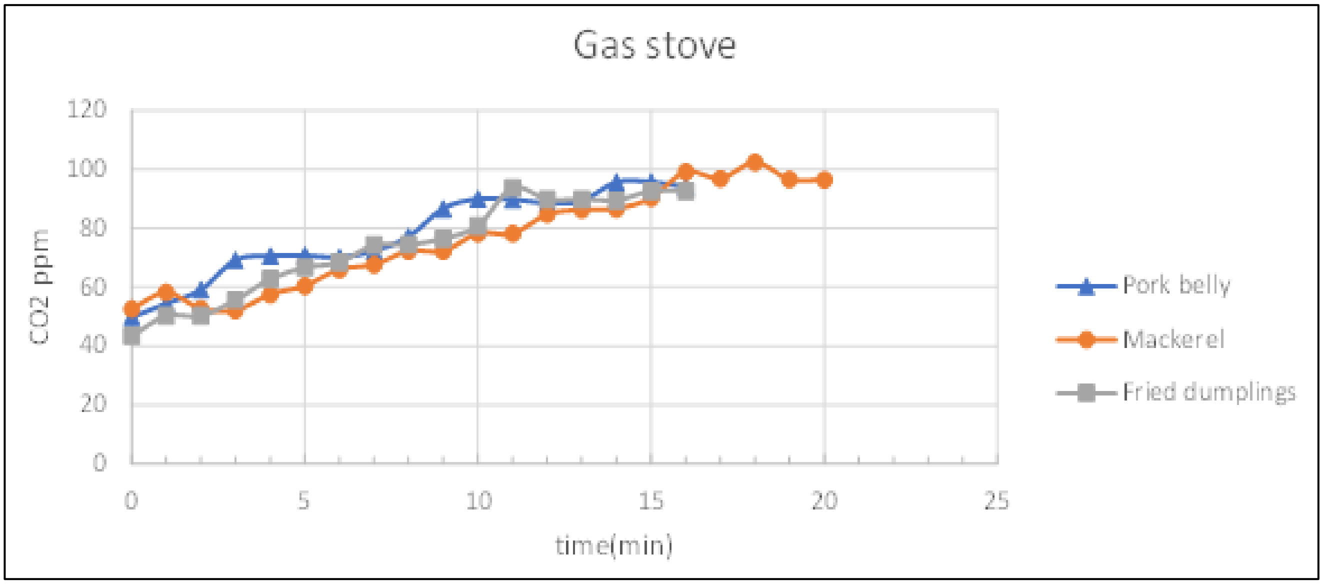

Figure 14: Changes in CO_2 concentration in a kitchen in an unventilated confined space

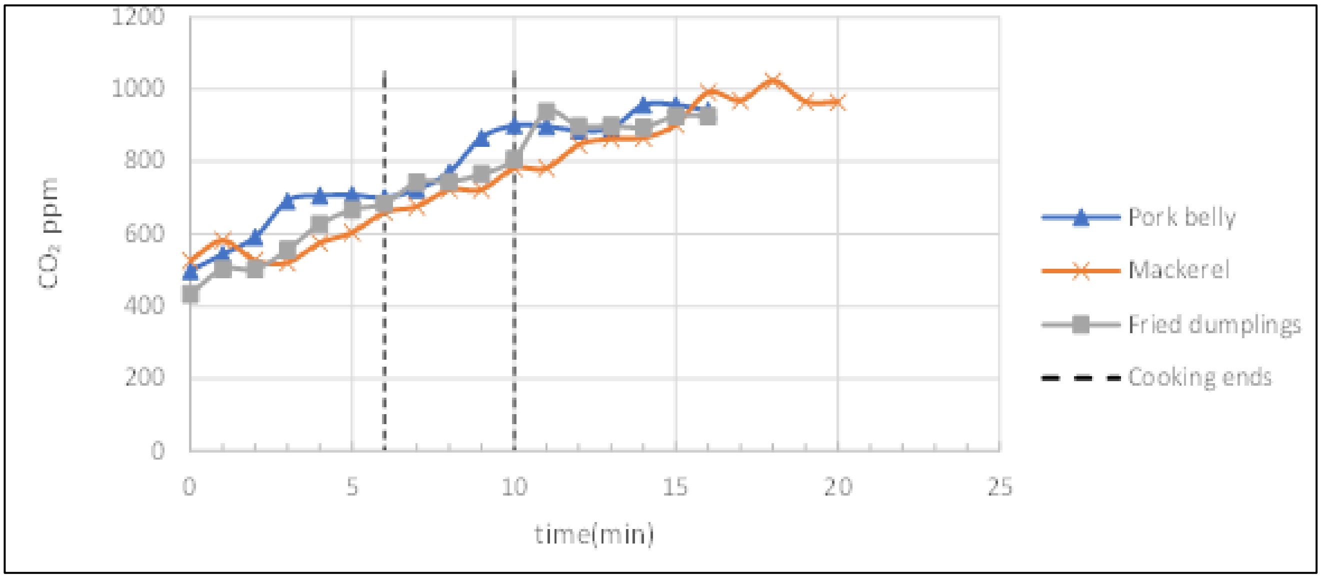

Figure 15: Changes in CO_2 concentration in a kitchen in an unventilated confined space

In the sealed space, which showed the highest generation rates, carbon dioxide levels increased over time in both the kitchen and the room. On average, carbon dioxide concentrations rose by 2 times in the kitchen and 1.76 times in the room. Among these, the highest concentration was observed during mackerel cooking in the kitchen, reaching 1024 ppm. Considering that the indoor air quality management standard is 1000 ppm, the carbon dioxide generated during cooking appears to be within a range that could be manageable and potentially excludable from strict indoor air quality control considerations.

4. Reflection

In this study, measuring the concentration of harmful substances during indoor cooking revealed the highest concentrations when no ventilation was used, with decreasing concentrations observed in the following order: range hood operation with both windows open, and then range hood operation alone. This suggests that combining mechanical and natural ventilation during indoor cooking is more effective for managing indoor air quality.

A similar result was found in a study by Lee Myung-gu et al. (2018), which conducted an experiment cooking 170g of pork belly and mackerel for 6 minutes. For pork belly cooking, PM-2.5 concentrations were measured at 92 µg/m³ with natural ventilation, 136 µg/m³ with range hood at 1st speed (0.018 m³/sec), and 94 µg/m³ at 2nd speed (0.026 m³/sec). For mackerel cooking, PM-2.5 concentrations were 1,290 µg/m³ with natural ventilation, 2,230 µg/m³ at 1st speed, and 1,400 µg/m³ at 2nd speed, showing similar reduction rates with natural ventilation and range hood at 2nd speed.

Compared to the previous study, this research uniquely applied both natural and mechanical ventilation simultaneously, with the hood's suction volume being 8 m³/min (0.133 m³/sec). Despite these differences, both studies demonstrate that combining mechanical and natural ventilation provides superior indoor air quality improvement compared to mechanical ventilation alone. These results suggest that for effective air quality management during indoor cooking, it is advisable to operate a range hood alongside opening windows for natural ventilation.

When using only the hood for ventilation, the particulate matter residual rate in the room was found to be higher than in the kitchen. This spatial difference is analyzed to stem from variations in ventilation methods. In the kitchen, continuous ventilation is provided by the range hood operation, whereas the room is a sealed space without a separate ventilation system, causing particulate matter to spread and remain stagnant for an extended period. Moreover, when no ventilation is used or only the range hood is operated during cooking, particulate matter concentrations and residual rates increased not only in the kitchen but also in the room. This suggests that particulate matter generated during cooking can spread throughout the living space and can remain for an extended time in spaces without appropriate ventilation systems. Therefore, this study highlights the importance of managing air quality not just in the kitchen but also in adjacent living spaces during home cooking.

The limitations of this study are as follows. First, the research used a limited number of experimental ingredients and cooking methods. The study measured harmful substance generation by grilling only three ingredients: mackerel, pork belly, and dumplings. Consequently, these findings may be insufficient to represent the overall characteristics of harmful substances generated during various cooking processes. Second, while the study focused on comparing harmful substance concentrations according to ventilation methods, it did not consider conditions such as temperature and humidity during cooking, or external environmental conditions like wind direction and speed during ventilation. Third, the measurement was conducted over a short duration. Harmful substance concentrations were measured only during cooking and for 10 minutes afterward, limiting the ability to evaluate long-term changes or accumulated impacts on indoor air quality. Therefore, follow-up research is necessary that includes various conditions more reflective of actual living environments.

5. Conclusions

This study aimed to analyze the impact of cooking ventilation methods on indoor air quality in the kitchen and adjacent rooms, and to provide guidelines for minimizing indoor air pollution.

Research results showed that harmful substance reduction rates were highest when using range hood and natural ventilation combined, followed by range hood operation alone, and lowest when no ventilation was employed. For carbon dioxide, the maximum concentration in a sealed kitchen was 1,024 ppm. This level is similar to the indoor air quality management standard of 1,000 ppm for multi-use facilities and does not pose a significant problem from a general indoor air management perspective. However, special attention is needed when vulnerable populations such as the elderly, children, or pregnant women reside in the home.

Particulate matter generation varied by cooking food, with mackerel showing the highest emission levels. This is attributed to mackerel's high unsaturated fat content.

Spatial particulate matter residual analysis revealed that when using only the range hood, PM-10 and PM-2.5 residual rates were 55.52% and 53.72% in the kitchen, but significantly higher at 96.79% and 98.46% in the adjacent room. Similar high residual rates were observed in sealed spaces. This difference is interpreted as continuous ventilation through the range hood in the kitchen, while the room lacked separate ventilation means, creating an environment similar to a sealed space.

In sealed spaces, particulate matter residual rates were 76.1% and 82.02% in the kitchen, and 96.48% and 94.47% in the room.

These research findings suggest that air quality management is crucial not only in the kitchen but also in adjacent living spaces during cooking. To effectively improve indoor air quality, simultaneous use of range hoods and natural ventilation is necessary during cooking.

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