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# Air Pollution Problems in Apartments Equipped with Gas Stoves

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**Abstract:** This article considers issues related to air pollution in residential apartments equipped with gas stoves. The combustion products from gas stoves are released directly into the indoor air, where people can spend a significant part of their time. Even relatively low concentrations of harmful substances contained in combustion products can pose serious health risks and potentially threaten lives. The detrimental effects of nitrogen oxides ($NO_x$) on human health and the environment are briefly analyzed. A comparison and analysis of legal regulations and standards regarding the maximum permissible concentration of $NO_x$ in the air across various countries are conducted. Theoretical calculations estimating the potential $NO_x$ levels in gas-equipped kitchens are presented. Additionally, the results of experimental studies measuring the $NO_x$ concentrations in the air of apartments with different gas stove designs, burner types, and ventilation methods are presented. The authors' data are compared with existing data from other similar studies.

**Keywords:** residential apartments; gas stoves; fuel combustion; combustion products; harmful substances; nitrogen oxides

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Academic Editors: Ludovico Danza and Carla Balocco

Received: 30 January 2025
Revised: 7 March 2025
Accepted: 14 March 2025
Published: 18 March 2025

**Citation:** Shkarovskiy, A.; Maliszewska, A. Air Pollution Problems in Apartments Equipped with Gas Stoves. *Energies* **2025**, *18*, 1492. https://doi.org/10.3390/en18061492

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## 1. Introduction

Natural gas is used in energy production and various industries, including the chemical sector, where it is essential for the production of ammonia and fertilizers, the production of hydrogen, as well as glass, steel, and plastic. Gas-powered vehicles are also becoming increasingly popular. Gas stoves are incomparably less powerful devices, but they affect the lives of millions of people across all countries [1].

The prospects for the development of the natural gas market depend on many factors. This is influenced by changing trends in the industry, the situation on the international market, and government policy. The European Union is striving to achieve ambitious goals related to climate neutrality. Therefore, the EU is gradually moving towards reducing the role of natural gas in the energy balance in favor of renewable energy sources (RESs), hydrogen, and biomethane.

Initially, it was expected that gas would quickly diminish in the energy sector in the escalating energy crisis driven by rising gas prices and decisive moves towards green energy. However, recent analyses and ongoing investments indicate that it will remain an important part of the energy system for the foreseeable future.

The International Energy Agency (IEA) predicts that gas consumption in the energy sector will peak between 2030 and 2035. Following this peak, a gradual decline in consumption is expected due to the increasing share of renewable energy sources. This indicates that natural gas will continue to be a crucial fuel supporting the energy system for at

least several decades, particularly given the context of the instability of renewable energy sources [2]. New renewable energy installations will not be able to completely replace fossil fuel energy until investments are made that stabilize the system and equalize the energy balance, as well as ensure the efficient transmission and rational use of energy.

Until then, gas-fired power plants and municipal energy systems will provide significant support to the entire system, thanks to their flexibility and ability to quickly respond to the volatility of renewable energy sources (e.g., wind or solar). Therefore, gas is considered an important stabilizer in a system based on renewable energy. This is particularly true in regions with intensive renewable energy development, such as Europe. Despite the increasing pressure for decarbonization, the complete exclusion of gas from the EU economy is unlikely, even after carbon neutrality is achieved. Given its advantages, natural gas can play an important role as a transition fuel, facilitating the gradual transition to cleaner energy sources.

The replacement of hundreds of thousands of gas stoves with electric ones is highly unlikely and technically and economically unjustified. The conclusions drawn above prove the plans for the development of gas infrastructure in many countries. For instance, Poland's national development plans foresee an accelerated expansion of gasification. It is anticipated that the number of households relying on gas fuel for their energy needs, including cooking, will continue to increase [3]. The consistent implementation of these plans is evidenced by the fact that, since July 2016, the Polish Gas Company has signed over 240 memorandums of understanding with local authorities regarding gasification [4].

In 1997, 56% of Polish households utilized natural gas stoves for cooking, while approximately 14% relied on liquefied petroleum gas (LPG) [5]. Progress is evident in data from 2015, which show that nearly 58% of users had gas–electric stoves (with an electric oven), and about 31% used entirely gas stoves [6].

The use of any organic fuel inevitably results in the emission of harmful substances produced during combustion. In the case of boiler plants, combustion products are released into the atmosphere through chimneys, facilitating their dispersion in the air [7]. However, the combustion products from household gas stoves are directly introduced into the indoor air of residences. Individuals can spend a significant part of their lives in this environment. Even relatively low concentrations of harmful substances in the air of apartments can pose a serious threat to human health and safety [8]. Therefore, the issue of air pollution in gas-heated apartments necessitates thorough analysis.

## 2. Problem Analysis

Gas stoves are used in millions of homes around the globe. The combustion of gas in these stoves releases hazardous pollutants directly into indoor air, including nitrogen oxides ($NO_x$), benzene ($C_6H_6$), carbon monoxide (CO), formaldehyde ($H_2CO$), and other harmful substances. Some tests have even detected solid particulates in the exhaust gases [9]. While the emissions of most pollutants are minimal and can be mitigated through improved design and proper burner adjustments, nitrogen oxides are particularly concerning, as they are produced even under optimal combustion conditions.

Until the latter half of the 20th century, nitrogen oxide emissions from fuel combustion received minimal attention. It was widely believed that the oxidation of atmospheric nitrogen at temperatures between 1500 and 1800 °C was negligible. As a result, the earliest publications addressing the theory of nitrogen oxide formation primarily focused on nuclear explosions in the atmosphere [10]. However, it was in these works that the "thermal" theory of nitrogen oxidation in flames, known as Zeldovich's Theory, was developed and experimentally validated.

Of the large group of compounds in this class, the most significant during fuel combustion are nitrogen monoxide (NO), also known as nitrogen oxide (II), and nitrogen dioxide $NO_2$, also known as nitrogen oxide (IV). The formation of these compounds is inevitable due to the high-temperature oxidation of atmospheric nitrogen that occurs during fuel combustion.

The flame primarily produces nitrogen oxide, accounting for approximately 95% of the emissions. NO is a colorless gas with a pungent odor. Although it is an irritant, it is significantly less harmful than nitrogen dioxide. As a highly reactive radical, nitrogen oxide in the atmosphere is rapidly oxidized to $NO_2$; in fact, just 30 s is sufficient for 92% of NO that comes into contact with air to convert into nitrogen dioxide [11]. It is important to note that the flue gases from small- and medium-power boilers can contain 106–160 ppm of $NO_x$. In the case of power boilers, this concentration can even be several times higher.

Over time, medical studies have demonstrated that even minimal concentrations of nitrogen oxides in inhaled air pose significant risks to both human health and the natural environment [1,12,13]. Nitrogen dioxide is highly reactive chemically, making it particularly hazardous to living organisms.

Already at a concentration of 0.53 ppm for 10–12 days, nitrogen dioxide inhibits plant growth and reduces productivity. Even with short-term exposure at concentrations of 8 ppm, $NO_2$ irritates the conjunctiva and mucous membranes of the nose and throat [14]. Symptoms of the toxic effects of this substance manifest relatively quickly, as it enters the body through the respiratory tract, bypassing the liver, the primary metabolic organ.

Prolonged exposure to $NO_2$, particularly at higher concentrations in inhaled air (>53 ppm), is associated with an increased risk of asthma in children, as well as a heightened risk of developing chronic obstructive pulmonary disease, lung cancer, premature birth, and diabetes. The dangers posed by nitrogen oxides to human health, in comparison to other known toxic substances found in exhaust gases, are summarized in Table 1 [15,16].

**Table 1.** Comparison of the impacts of some toxic substances on humans [15,16].

| The Time of Exposure and the Nature of the Action | Content in Inhaled Air, % vol. | | |
|---|---|---|---|
| | **$NO_x$** | **$SO_2$** | **CO** |
| Several hours without noticeable effect | 0.0008 | 0.0025 | 0.01 |
| Signs of mild poisoning | 0.0010 | 0.005 | 0.01–0.05 |
| The possibility of serious poisoning in 30 min | 0.005 | 0.008–0.015 | 0.2–0.3 |
| Danger to life in case of short-term exposure | 0.015 | 0.06 | 0.5–0.8 |

Nitrogen dioxide is associated with a wide range of harmful effects, not only on humans but also on all forms of life. As an acid-forming oxide, it contributes to the degradation of both the natural environment and man-made structures. Nitrogen dioxide plays a significant role in the phenomenon of photochemical smog. When exposed to radiation with a wavelength of less than 0.38 µm, $NO_2$ dissociates, resulting in the formation of atomic oxygen. This initiates photochemical reactions that produce even more harmful chemical compounds, such as peroxyacetyl nitrate (PAN) and peroxybenzene nitrate (PBN) [17].

Paradoxically, most countries worldwide do not specify permissible levels of nitrogen oxide concentration in the air for residential buildings. This paper aims to investigate this issue both normatively and experimentally. This study continues a long-term series of research conducted by the authors' team [3,8].

## 3. Research Methods and Experimental Objects

The objectives outlined above have led to three distinct research directions:

I. Research on the standards and regulations of the European Union and other countries that impose restrictions on the concentration of nitrogen oxides in the atmosphere or in occupational environments;

II. Analysis of the available literature data on air pollution in apartments with nitrogen oxides for the purpose of a subsequent comparison with the data from our own measurements;

III. Experimental studies on pollutant emissions in apartment kitchens equipped with gas stoves, compared to results from similar studies known to the authors. The experimental program was divided into several distinct stages, based on the type of gas equipment and the methods used for removing combustion products:

1. Standard modern gas stove with an open flame:
   (a) Using traditional gravity ventilation in the kitchen area;
   (b) Using an additional hood above the stove;
2. Flame-under-glass gas stove:
   (a) Using traditional gravity ventilation in the kitchen area;
   (b) Using an additional hood above the stove.

Stage III-1 measurements were conducted under laboratory conditions that simulated a kitchen with a cubic capacity of approximately 14.0 $m^3$. The kitchen was situated on the top floor of a seven-story building. It was equipped with a standard four-burner BEKO gas stove, complete with an oven. The burner power and natural gas consumption (Wobbe index: Iw = 45.7 to 54.7 $MJ/m^3$) were as follows:

- Small burner—1 kW (79.6 $dm^3/h$);
- Two regular burners—1.9 kW (151.3 $dm^3/h$);
- Large burner and oven burner—3.0 kW (238.9 $dm^3/h$).

The room featured a 14 cm by 14 cm gravity ventilation channel and a window measuring 172 cm by 142 cm, which included a tilting/opening section. During stage III-1b, a ventilation hood with a maximum capacity of 50 $m^3/h$ was activated above the stove.

The measurements of the III-2 stages were conducted under identical conditions in a kitchen equipped with a ceramic gas stove, the GPC 3T model, which features a flame-under-glass design by SOLGAZ. This stove is equipped with three burners that have a total capacity of 5.45 kW and includes a mechanically ventilated space beneath the cooking surface, allowing for the discharge of combustion products into a room adjacent to the wall. In all variants, the chemical analysis of the exhaust gas composition and airborne pollutants ($O_2$, $CO_2$, CO, $NO_x$) was conducted using equipment that provides real-time measurement results. To ensure the reliability of the obtained results, measurements were conducted using two gas substance meters, a Nanosens DP-24 recorder, an MRU exhaust gas analyzer, and a TESTO multifunction device. All devices are regularly calibrated using reference gases in accredited laboratories. The characteristics of the main gaseous substance meters used during the tests are presented in Table 2.

**Table 2.** The characteristics of the main gaseous substance meters used during the tests.

| **Device Name** | **Gaseous Substance Meter** | |
|---|---|---|
| Type | DP24 NO—$NO_2$ | |
| Detected medium | Nitrogen oxide (NO) | Nitrogen dioxide ($NO_2$) |
| Measuring range ± | 0–200 | 0–20 |
| Accuracy | 0.2 | 0.02 |
| Unit | ppm | |

The measurement results obtained during the study were statistically analyzed to eliminate both systematic and random errors. The experiment was designed as a one-variable (one-factor) study. The response variable, measured as $NO_x$ concentration readings at fixed time intervals, was analyzed in relation to the amount of gas burned, which was linearly dependent on time. The size of the test sample, serving as a pilot, was determined based on technical and economic considerations. To assess the repeatability of the results, the experiment was conducted five times under consistent conditions of temperature, pressure, and humidity. Readings taken at analogous time intervals were compared, and the results were standardized by calculating the average for these intervals. For each time point across the experimental repetitions, the standard deviations from the average at individual measurement time points were compared. The standard deviation was calculated with known measurement accuracy.

The measurements were performed in the period 15 November 2023–29 November 2023 and (after analyzing the results obtained and correcting the research program) in the period 12 May 2024–16 May 2024.

## 4. Results and Discussion

### *4.1. Analysis of Legal Regulations*

The regulations currently in effect in Poland [18] for premises designated for long-term human occupancy establish permissible concentration limits for only a limited number of harmful substances. However, these regulations do not address nitrogen dioxide, which, as numerous studies indicate, can be generated in concentrations that pose a risk to occupants even during the normal operation of gas stoves [1,12,13].

The maximum permissible concentrations of harmful substances in the working environment [19] are defined in greater detail and include 556 substances. It is interesting that the permissible concentration standards for carbon monoxide in residential areas are significantly stricter than those for outdoor air.

A comparison of Polish standards for permissible concentrations of carbon monoxide and nitrogen dioxide emitted during the operation of gas appliances is presented in Table 3 [18–20]. The permissible concentrations of these compounds in various countries are detailed in Table 4 [21–28].

**Table 3.** The maximum concentrations of harmful substances permissible in the atmosphere prescribed by Polish legislation [18–20].

| No. | Chemical Name and CAS Number | Exposure Time | Permissible Concentrations | | | | |
|---|---|---|---|---|---|---|---|
| | | | Internal Environment | | | External Environment [20] | |
| | | | Intended for Human Habitation, Housing [18] | Working Area [19] | | | |
| | | | | Threshold Level Value | Threshold Level Value, Acute Exposure | Threshold Level Value | Threshold Level Value, Acute Exposure |
| 1 | Carbon monoxide (630-08-0) [ppm] | for 15 min | - | | 100.4 | - | - |
| | | for 30 min | 8.6 | - | - | - | - |
| | | for 8 h | 2.6 (average daily) | 19.7 | - | 8.6 | - |
| 2 | Nitrogen dioxide (10102-44-0) [ppm] | for 15 min | - | - | 0.78 | | - |
| | | for 1 h | - | - | - | 0.105 | - |
| | | for 8 h | - | 0.36 | - | - | - |
| | | for 1 year | - | - | - | 0.021 | - |

**Table 4.** The maximum concentrations of harmful substances permissible in the atmosphere prescribed by selected countries' legislation [21–28].

| No. | Chemical Name | WHO (AQG Level) [21] | NIPH (Norway) [22] | Canada [23] | China [24] | U.S. EPA [25] | Russia [26] | France [27] | EU (Air Quality Directives) [28] |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Carbon monoxide (630-08-0) [ppm] | 86 (15 min) | 68.6 (15 min) | - | - | - | - | 86 (15 min) | - |
| | | - | - | - | - | - | 4.29 (20 min) | 51.5 (30 min) | - |
| | | 30 (1 h) | 21.5 (1 h) | 24.5 (1 h) | 8.6 (1 h) | 30 (1 h) | - | 25.7 (1 h) | - |
| | | 8.6 (8 h) | 8.6 (8 h) | - | - | 9 (8 h) | - | 8.6 (8 h) | 8.6 (8 h) |
| | | 3.4 (24 h) | 3.4 (24 h) | 9.87 (24 h) | 3.4 (24 h) | - | 2.6 (24 h) | - | - |
| 2 | Nitrogen dioxide (10102-44-0) [ppm] | - | 0.157 (15 min) | - | - | - | - | - | - |
| | | - | - | - | - | - | 0.044 (20 min) | - | - |
| | | 0.105 (1 h) | 0.052 (1 h) | 0.089 (1 h) | 0.105 (1 h) | 0.100 (1 h) | - | 0.105 (1 h) | 0.105 (1 h) |
| | | 0.013 (24 h) | 0.013 (24 h) | 0.011 (24 h) | 0.042 (24 h) | - | 0.021 (24 h) | | - |
| | | 0.005 (1a) | 0.005 (1a) | - | 0.021 (1a) | 0.053 (1a) | - | 0.010 (1a) | 0.021 (1a) |

When analyzing the values presented in the tables, it is important to note that the European standards defining the average permissible concentrations of nitrogen dioxide ($NO_2$) in the air throughout the year are four times higher than the new recommendations set forth by the World Health Organization (Global Air Quality Guidelines, AQG). Additionally, these standards do not specify requirements for the average permissible concentrations of carbon monoxide (CO) over the course of the year. Furthermore, the permissible level of CO in outdoor air, based on an eight-hour average, is more than three times higher than the values established in the current standards for indoor air.

### *4.2. Review of Research Data in a Related Field*

Numerous studies conducted worldwide indicate that the levels of nitrogen oxides in apartments with gas stoves can significantly exceed acceptable or recommended standards. For further analysis and comparison, the studies most relevant to the experimental conditions of this research were selected.

Figure 1 presents the findings of the research conducted by the Slovak team [29]. We compared these results to the World Health Organization (WHO) guidelines and European air quality directives.

Figure 2 presents the results of research conducted by a team of U.S. scientists, which indicated that the $NO_x$ concentration in the air was approximately two times lower [9]. This reduction may be attributed to various types of cookers and differing ventilation conditions. Similar to the previous case, the results are compared in accordance with WHO guidelines and European air quality directives.

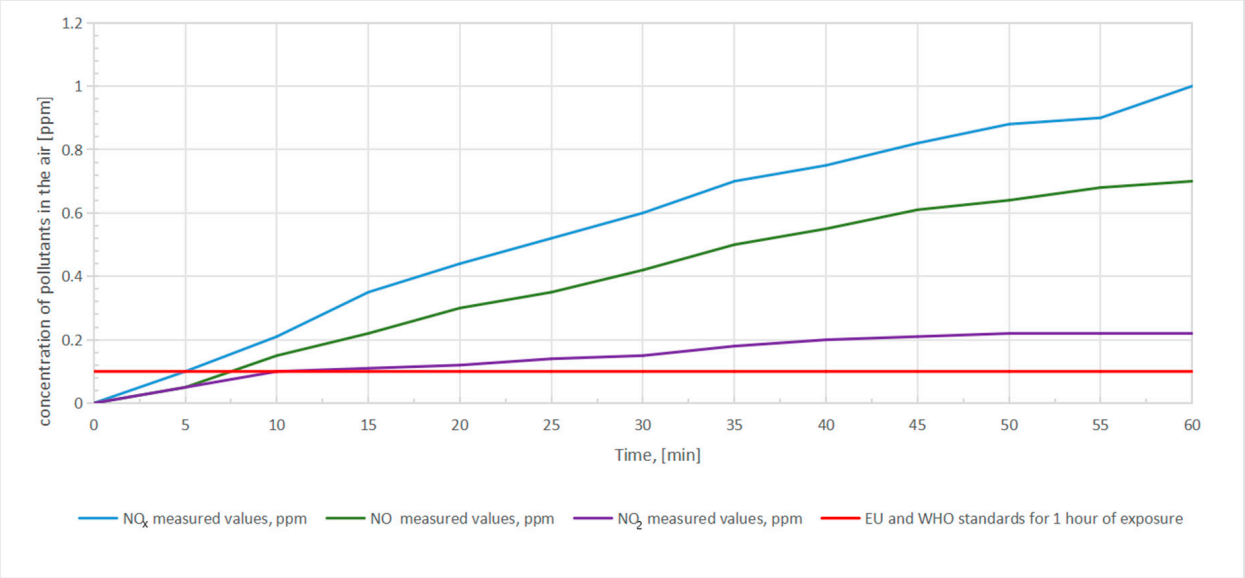



**Figure 1.** Concentration of nitrogen oxides in the kitchen according to tests [29] compared to WHO guidelines and European air quality directives.

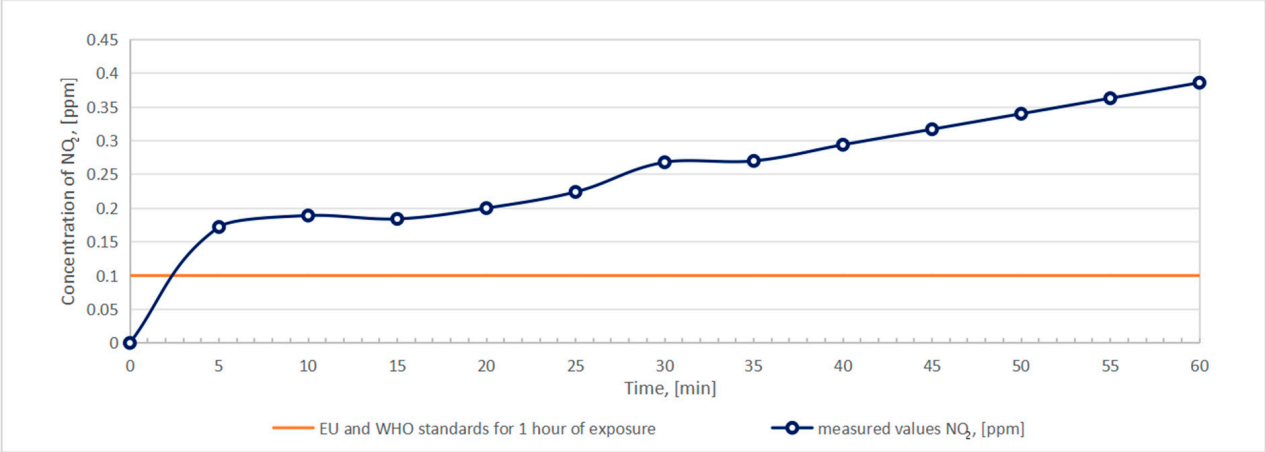



**Figure 2.** Concentration of nitrogen oxides in the kitchen according to tests [9] compared to WHO guidelines and European air quality directives.

A group of Portuguese scientists conducted a study in several apartments in Porto and Aveiro, Portugal [30]. The study used a different analytical approach by determining the ratio of the nitrogen dioxide ($NO_2$) concentrations in indoor and outdoor air. The results revealed that the $NO_2$ levels in some apartments equipped with gas stoves were three times higher than those found in outdoor air. Conversely, in apartments with electric stoves, the ratio favored indoor air (Figure 3).

The issue of low efficiency in the natural ventilation of residential spaces and its limited impact on indoor air quality is widely acknowledged. This problem is exacerbated during the winter months when ventilation is further reduced. Homeowners frequently attempt to minimize heat loss to decrease heating costs, leading to inadequate ventilation. Consequently, many residential areas are nearly devoid of proper airflow, as the airtightness of modern windows and doors prevents sufficient outside air from entering.

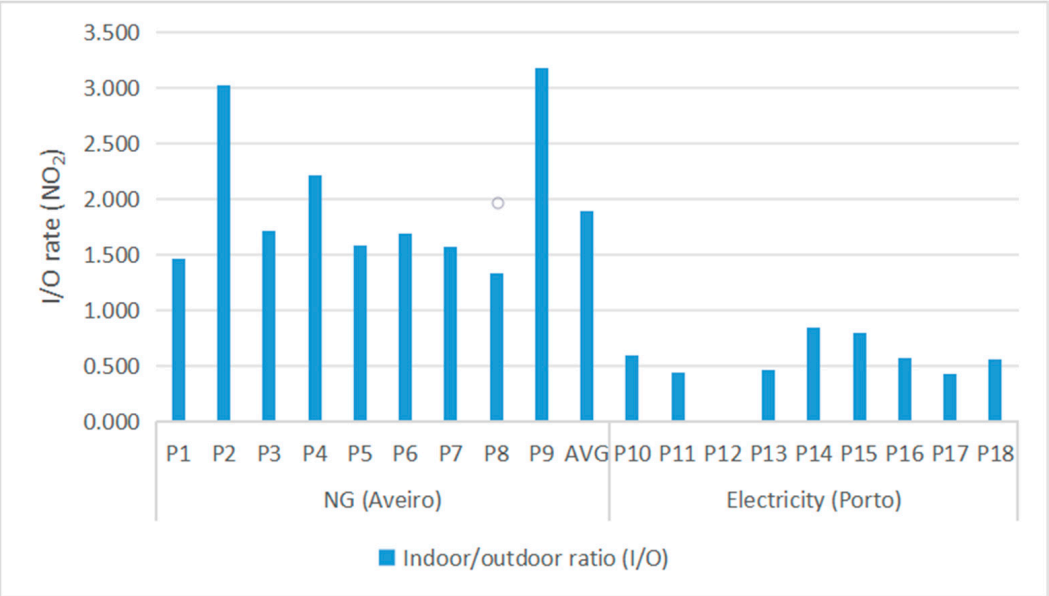



**Figure 3.** Ratios of indoor to outdoor $NO_2$ concentrations for residential buildings [30]: P1–P18—the numbers of surveyed apartments. NG—apartments with gas stoves (AVG—average indicator). Electricity—apartments with electric stoves.

Mechanical ventilation is undoubtedly more effective. For instance, the study referenced in [9] investigated the impact of mechanical exhaust on pollutant formation within a living space. The concentrations of nitrogen dioxide ($NO_2$) in the kitchen, with the exhaust system both activated and deactivated, are illustrated in Figures 4 and 5. The authors compare the results obtained with the standards set by the World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA) for one-hour exposure, as well as the WHO standard for 24 h exposure.

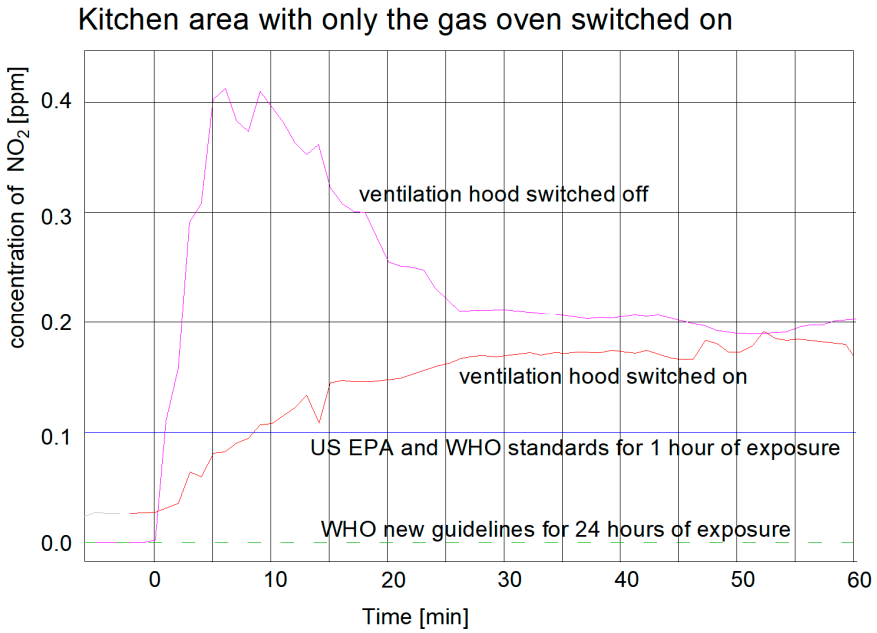



**Figure 4.** The influence of mechanical ventilation (hood) on the $NO_2$ concentration in the room (only the oven of the gas stove is on) [9].

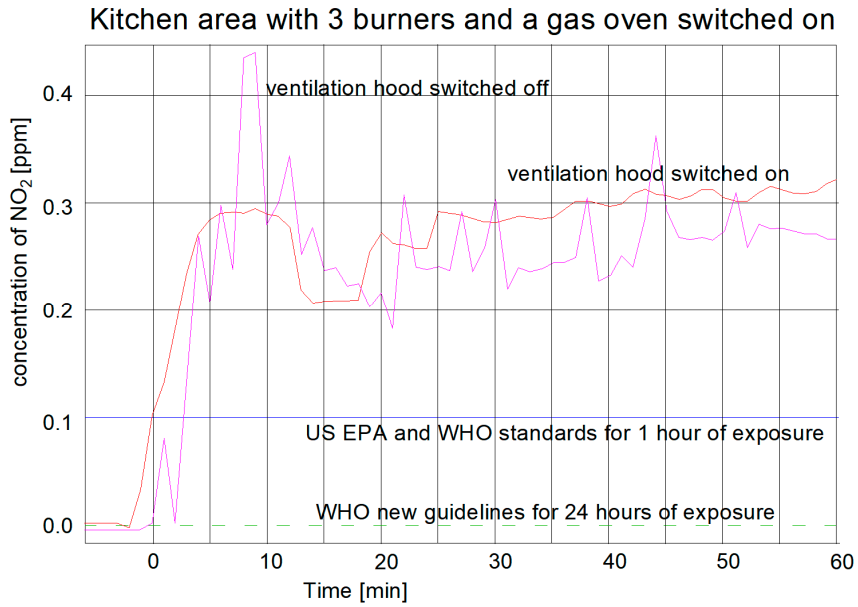



**Figure 5.** The influence of mechanical ventilation (hood) on the $NO_2$ concentration in the room (three burners and oven on) [9].

These studies have demonstrated that the level of ventilation efficiency varies significantly and is largely dependent on the performance of the fans, their positioning relative to the gas appliance, and the number of burners in use. At low and medium loads of the gas stove (Figure 4), the use of a range hood can substantially enhance the air quality in the kitchen, particularly during the first 20 min after the gas appliance is activated, when the concentration of $NO_2$ in the indoor air increases markedly. Over time, however, the efficiency diminishes due to the accumulation of combustion products in stagnant areas of the room. At high loads (Figure 5), the effectiveness of a standard-performance range hood becomes negligible.

In general, assessing $NO_2$ exposure based on direct measurements of indoor concentrations is challenging. The literature on this topic is limited, and the observed concentrations can vary significantly depending on factors such as the ventilation efficiency and stove usage patterns. Furthermore, studies often overlook the impact of parameters like the room size and apartment layout, which can greatly influence the concentration of nitrogen oxides throughout the entire apartment.

Therefore, an analysis of the available research indicates that even with the normal use of gas stoves, the levels of nitrogen oxides can significantly exceed the permissible limits established by the EPA and WHO. This is particularly concerning, as we spend the majority of our lives in residential environments, and even relatively low concentrations of harmful substances over prolonged exposure can pose a serious health risk.

Our studies were designed to complement the analyzed data and clarify the impact of various influencing factors.

### *4.3. Calculation Stage*

Theoretical calculations for stage III-1 were initially conducted. By simultaneously operating medium and large burners with nominal powers of 1.90 kW and 3.00 kW, the natural gas consumption (with a calorific value of 37.60 MJ/m$^3$) can be determined as follows:

$$\frac{(1.9 + 3.0)10^3 \cdot 3600}{37.6 \cdot 10^6} = 0.469 \text{ m}^3/\text{h}$$

As stated in Section 4.1, the authors were unable to locate any current standards regarding the nitrogen oxide content in the combustion products of domestic gas stoves. The only existing requirement is found in the archival standard [31]. The $NO_x$ content standard referenced therein (200 $mg/m^3$) pertains to dry, undiluted combustion products with an excess air coefficient of $\alpha = 1.0$. By considering the theoretical specific volume of dry combustion products, which is 8.52 $m^3$ per $m^3$ of gas [32], we can estimate the flow of combustion products entering the room:

$$0.469 \cdot 8.52 = 3.996 \text{ mg/h}$$

In turn, this allows us to estimate the flow of nitrogen oxides entering the kitchen area:

$$3.996 \cdot 200 = 799.2 \text{ mg/h}$$

The required air exchange rate in a gas-fueled kitchen with a window should be at least 70 $m^3/h$ [33]. Based on this rate, the $NO_x$ can be directly estimated in the air of the room:

$$\frac{799.2}{70} = 11.42 \text{ mg/m}^3$$

The standards of certain countries stipulate a higher air exchange requirement of up to 90 $m^3/h$ [8]. Consequently, the calculated result is slightly lower at 8.88 $mg/m^3$ (4.72 ppm).

Since there are no established standards for nitrogen oxide levels in residential premises, the results obtained can only be compared to the requirements for workplace environments [19]. Specifically, this comparison is made within the range from the TLVwa (Threshold Limit Value for working areas) to the TLVae (Threshold Limit Value for acute exposure). From this perspective, it is noteworthy that the Polish TLVwa value for $NO_2$ (0.36 ppm), which is typical for European countries, is significantly exceeded. Additionally, the highest known Russian standard TLVae for $NO_x$ (2.66 ppm) has also been exceeded.

However, this is the maximum allowable concentration for an exposure not exceeding 15 min. A person can remain in the kitchen for a much longer duration. These approximate calculations convincingly underscore the necessity for the experimental verification of air pollution in gas-heated apartments resulting from the combustion products of household gas stoves.

### *4.4. Experimental Research*

The measurements were conducted in a kitchen with a volume of approximately 14.0 $m^3$, featuring a traditional open-flame gas stove with four burners and an oven, which together have a total power output of 10.8 kW (stage III-1). During the stage III-2 studies, the kitchen was fitted with a three-burner gas stove of the flame-under-glass type, providing a total power of 5.45 kW.

Although the tests for nitrogen oxide and carbon monoxide concentrations have standardized determination methods, equipment capable of providing real-time measurement results was utilized to analyze air pollutants.

To assess the specific impact of the gas stove, the measurement point was selected at a distance of 0.5 m from the stove and at a height of approximately 1.20 m above the floor. The burner operated for a duration of 60 min during the measurement period. The airflow measured in the natural ventilation duct during this time was approximately 20 $m^3/h$.

Figure 6 illustrates the beneficial impact of using a hood under similar operating conditions of a gas stove. In contrast to the data analyzed previously [9], our studies demonstrate a consistent effect of the hood, resulting in a three-fold reduction in the

concentration of $NO_x$ in the air. This further reinforces the significant dependence of the results on the experimental conditions.

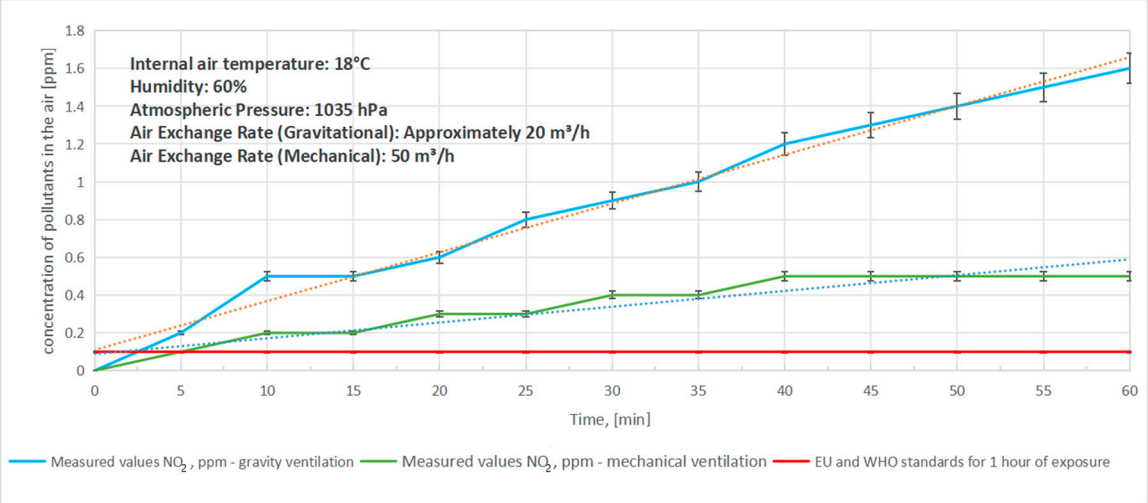



**Figure 6.** Results of measurements of nitrogen oxide concentrations in the kitchen using natural and mechanical ventilation.

It is important to note that the use of mechanical ventilation does not decrease the concentration of nitrogen oxides in the air of gasified apartments, even to the level of one hour of exposure.

Of particular interest was the comparison of gas analyzer readings for the nitrogen dioxide ($NO_2$) content in the air and the total concentration of nitrogen oxides (NO and $NO_2$), collectively referred to as $NO_x$, which is determined by the conditional oxidation of nitrogen oxide to nitrogen dioxide (Figure 7). The discrepancy in the results indicates a persistent presence of a significant proportion of nitrogen oxide in the air, despite its rapid oxidizability. This phenomenon can be attributed to the continuous influx of new nitrogen monoxide (NO) into the atmosphere during the ongoing operation of the burners. In a certain sense, this can be viewed as a positive aspect because, as previously noted, NO is considerably less harmful to humans than $NO_2$.

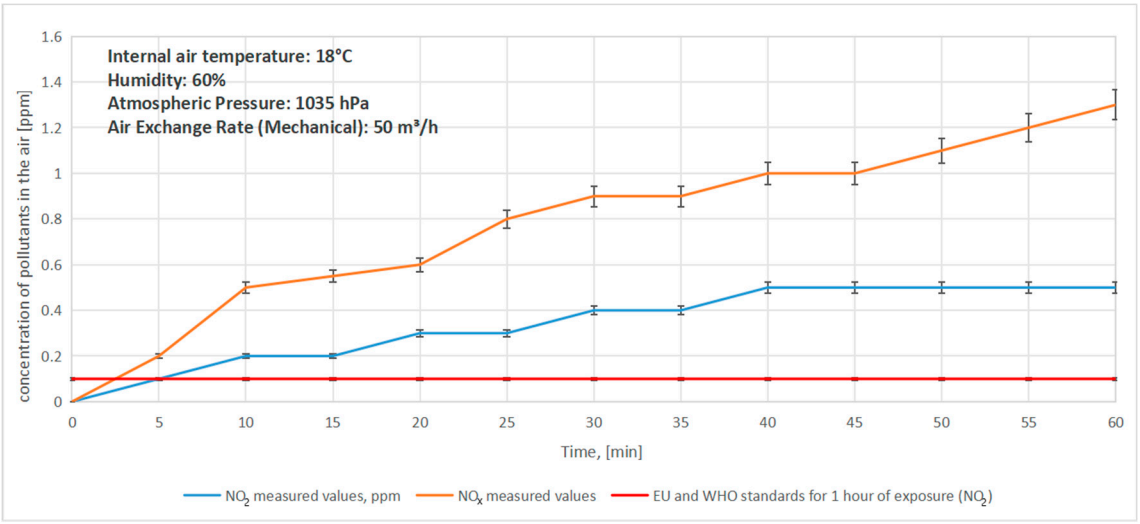



**Figure 7.** Comparative analysis of the contents of $NO_2$ and $NO_x$ in the air of the kitchen.

The next stage of the study was to examine the impact of the gas stove design on the concentration of nitrogen oxides in an enclosed space.

To conduct this study, a room with natural ventilation was equipped with two types of gas stoves: a traditional model featuring an open flame and a modern model with burners located beneath glass. The experiment was carried out on the same day over a duration of three hours. To ensure reliable results, the concentration of nitrogen dioxide ($NO_2$) was measured while operating one burner with a power output of 1 kW for each stove type. The results are illustrated in Figure 8. The data clearly demonstrate that the use of flame-under-glass stoves can reduce the concentration of $NO_2$ in inhaled air by 2–3 times. During the tests, the temperature of the glass plate was also determined using a DIT 500 pyrometer, with the maximum surface temperature reaching approximately 600 °C.

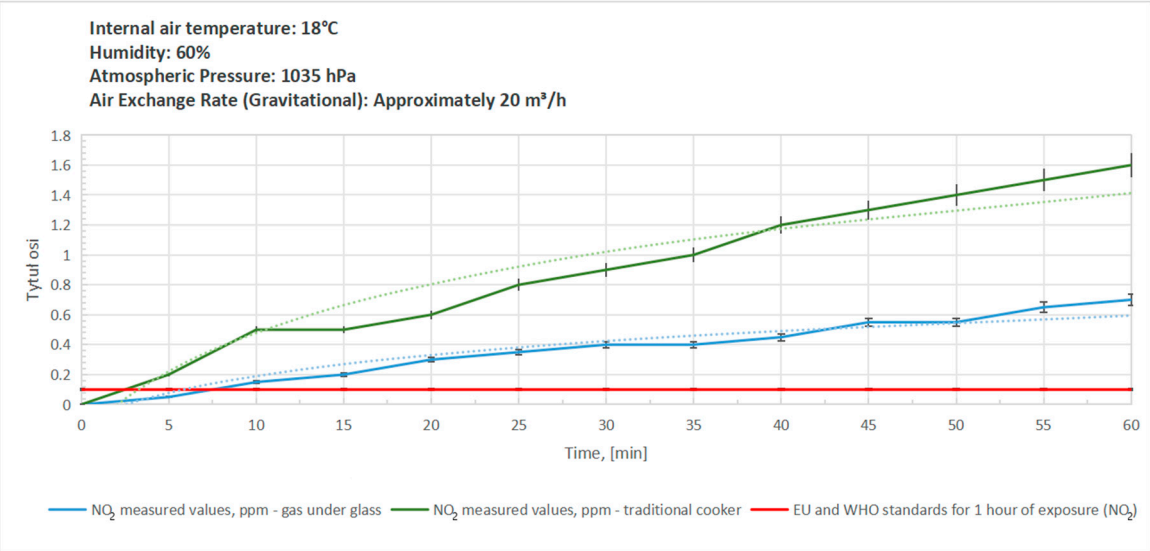



**Figure 8.** Comparison of air pollution levels during the operation of a traditional gas stove and a flame-under-glass stove.

## 5. Conclusions

Natural gas will undoubtedly be used as a reliable and widely available energy source for many more years. Therefore, we should prioritize its safe usage to ensure that we can feel secure in our homes without posing a genuine threat to our health and safety.

Gas stoves are a specific type of gas appliance. Firstly, they are the most common, and secondly, the combustion byproducts they produce are released directly into the air of apartments. Gas stoves are expected to remain in use for many years to come due to their convenience and relative affordability. They are particularly popular among the elderly and individuals with lower incomes, as this demographic is especially vulnerable to the long-term effects of nitrogen oxides, given that they spend a significant portion of their days indoors.

Research results indicate that, under average operating conditions of a gas stove, the nitrogen dioxide ($NO_2$) concentrations in kitchen air significantly exceed the safe levels recommended by the World Health Organization (WHO) and European air quality directives.

The natural ventilation systems commonly used do not facilitate adequate air exchange. In particular, the airflow within the natural ventilation ducts of apartments situated on the top floor is insufficient to effectively remove pollutants from the living space in a timely manner.

Mechanical ventilation significantly improves air quality; however, it is still not possible to achieve the levels recommended by the World Health Organization (WHO) and

European air quality directives. Furthermore, the values discussed pertain to outdoor air, as there are currently no standards applicable to indoor air in residential settings.

The challenge of ensuring adequate air exchange and the removal of pollutants through mechanical ventilation can be addressed by utilizing a hood with greater capacity.

The next crucial step in reducing $NO_x$ emissions in apartment air quality is the implementation of new technological solutions, such as flame-under-glass gas stoves. However, a significant drawback of this type of stove is its high cost and lower efficiency, which can lead to increased cooking times and higher gas consumption.

Undoubtedly, future studies will also consider additional factors that influence air quality related to gas cookers, such as PM2.5 emissions. Furthermore, they will examine factors affecting the distribution of pollutants and measurement readings including room geometry, measurement limitations, and external influences such as weather conditions and building characteristics.

**Author Contributions:** Conceptualization, A.S. and A.M.; Validation, A.S. and A.M.; Investigation, A.S. and A.M.; Data curation, A.M.; Writing—original draft, A.M.; Writing—review & editing, A.S. and A.M.; Visualization, A.S. and A.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** The authors declare no conflict of interest.

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