MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION

**Rocznik Ochrona Środowiska**

Volume 22. Year 2020 ISSN 1506-218X 915-926

# Impact of Weather Conditions on the Operation of Flue Gas Ducts and the Gravitational Ventilation in Rooms with Gas Appliances

*Agnieszka Maliszewska*
*Koszalin University of Technology, Poland*
*corresponding author's e-mail: agnieszka.maliszewska@tu.koszalin.pl*

## 1. Introduction

Contemporary systems for removing flue gases and used air should be selected so that there is no risk of accumulation of hazardous and harmful substances in human health. The use of energy from the combustion of organic fuel always involves the emission of compounds hazardous to health, which should be removed from the atmosphere of the room as soon as possible. We spend a significant part of our lives in apartments, and even relatively low concentrations of harmful substances can pose a serious threat to health. Efficient ventilation and an exhaust system is a guarantee of the safe use of gas appliances.

In Poland, flats are ventilated mainly in a gravitational way, where the exhaust takes place through gravitational ventilation channels, and the supply through disordered infiltration and ventilation. In this case, air exchange at the recommended level is very difficult to achieve. The efficiency of air exchange, and thus the concentration of harmful substances in rooms, largely depends on changing conditions – i.e. outdoor air temperature, atmospheric pressure, wind strength and direction, as well as the way the rooms are used.

## 2. Purpose of work and research methods

### 2.1. Purpose of research

Air is removed from the rooms as a result of the pressure difference between the room and chimney and the building's surroundings. This is the active pressure and expresses the so-called chimney draft, which is the basis for the operation of gravitational ventilation and proper operation of flue systems. The pressure value determines whether the combustion of fuel in gas appliances proceeds in the assumed way, the ventilation works properly, and the exhaust gases and used air do not tend to go back to the rooms (Larsen 2006).

The natural chimney draft depends on several factors, including:

- the difference in density of exhaust gas and air outside the building,
- construction, height and cross-sectional area of chimney,
- strength and direction of the wind,
- atmospheric pressure,
- building structure (roof) and building location relative to the other buildings, trees etc.
- terrain.

The proper operation of ventilation and flue systems depends on many variables whose interaction generates a large number of variants.

The author of the article set themselves the task of examining the impact of weather conditions on the operation of flue gas exhaust systems and ventilation in rooms with gas appliances.

### 2.2. Subject of study

In order to determine the impact of weather conditions on the chimney draft, the work of the ventilation and flue gas system in a 4-storey multifamily building located in Koszalin (II wind zone) (PN-EN 1991) was analyzed.

**Fig. 1.** Multifamily building with analysed apartments

Two apartments located on the ground floor and on the last floor were analysed. In each apartment there was a 4-burner gas cooker and a gas instantaneous water heater with a maximum power of 23.6 kW.

In the kitchen room, exhaust ventilation is carried out using a brick ventilation duct with a section of 140x140 mm, with a ventilation grille mounted under the ceiling. The air supply is carried out by means of an air grille installed in the door with a cross-section of 200x100 mm. Initially, the flats were fitted with ventilation hoods, however, due to the opinion of specialists citing the provisions of §150.9 of the Technical Conditions (Rozporządzenie 2002), they were abolished.

In the bathroom, the exhaust is carried out by means of a brick ventilation duct with a section of 140x140 mm, with a ventilation grille mounted under the ceiling. The air is supplied by means of an air grille installed in the door with a cross section of 200x100 mm.

Flue gas discharge from a gas flow water heater via a flue pipe Ø140 mm. The plan of the apartment is shown in Figure 2.

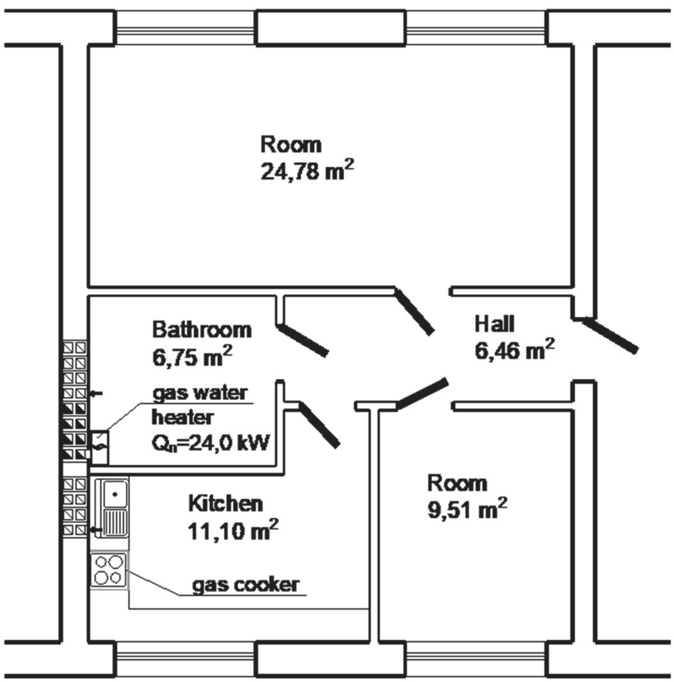


**Fig. 2.** Plan of a flat with gas appliances

## 2.3. Research methods and assumptions

### *2.3.1. Research methods*

In order to determine the impact of weather conditions, meteorological data was analysed covering the period of 24 months, from January 2018 to December 2019.

In addition, in the last quarter of 2019, the results obtained were compared with the actual state during local visits. For this purpose, the multifunctional meter Testo400 type was used to measure ventilation air parameters.

### *2.3.2. Assumptions*

The research assumed that due to the ajar window in the room and kitchen, the resistance to infiltration would be negligible, therefore their impact on the total value of displacement pressure was omitted. It was assumed that due to the short distance of the gas stove from the ventilation duct discharging used air, the air temperature in the duct will be 30°C. The bathroom has an air temperature of 25°C.

The flue gas temperature from the gas water heater is based on catalogue data and is 140°C

The required ventilation air flow for living needs was adopted on the basis of standards and it is 70 $m^3/h$ for kitchens and 50 $m^3/h$ for bathrooms (PN-83/B-03430+A3:2000).

Chimney draft disturbances are often a consequence of local atmospheric conditions, which determine the air flow around the building. Although wind is a factor conducive to chimney draft, under certain conditions it may cause a reduction or complete disappearance of the chimney draft. Such a phenomenon occurs especially often in the submontane (wind zone III) and coastal (wind zone II) regions (Żurański 2003).

To assess the impact of wind, it is necessary to know the external pressure exerted by the wind on the external surfaces of the building, as well as the pressure at the outlets of ventilation and flue pipes.

Due to the fact that the wind direction is characterized by high variability throughout the day, for the purposes of the analysis the wind blowing in the corner of the building was adopted. Windows, ventilation and exhaust ducts will be on the leeward side. The distribution of pressure coefficient values on the leeward façade and roof is shown in Figure 3.

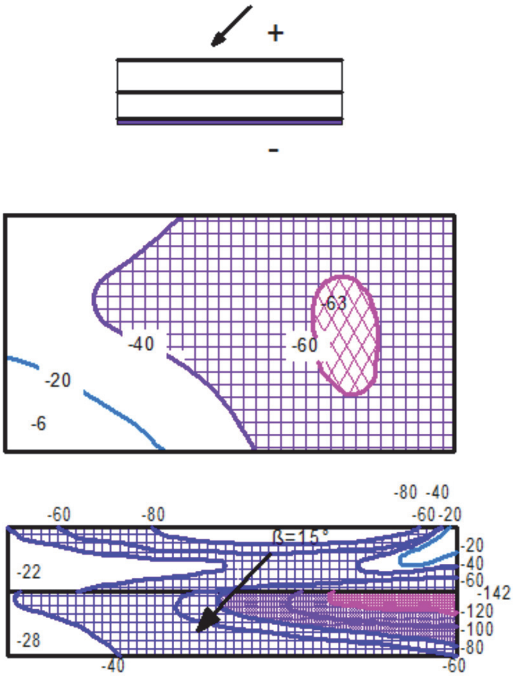


**Fig. 3.** Distribution of the value of the external pressure coefficient on the wall and roof of the building at the assumed wind direction (Jensen & Franck 1965)

## 3. Results of tests

The most adverse conditions and disturbances in the work of gravitational ventilation systems were observed in the summer. The equalization of outside and inside air temperatures is the main factor that interferes with proper air exchange in the room (Szkolenie 2014). In summer, however, the problem is not so much noticed, because users often open the windows, allowing fresh air to enter the rooms.

Abnormal operation of the ventilation system has already been observed at temperatures less than 10°C, especially in rooms located on the top floor. Sample results of the total positive displacement pressure and the actual exhaust ventilation air flow for the kitchen ventilation duct are presented in Table 1.

**Table 1.** Total pressure and actual air flows in the kitchen ventilation duct in 10.2019

| Date | T avg. [°C] | ρ [kg/m³] | Wind int. [km/h] | Pres. s. lev. [HPa] | Kitchen | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | $\Delta p_c$ [Pa] | | Vr [m³/h] | |
| | | | | | fourth floor | ground floor | fourth floor | ground floor |
| 03.10.2019 | 8.0 | 1.241 | 8.7 | 1007.3 | 1.015 | 4.752 | 38.03 | 45.61 |
| 04.10.2019 | 8.9 | 1.244 | 7.1 | 1012.8 | 0.995 | 5.099 | 37.64 | 47.24 |
| 05.10.2019 | 9.0 | 1.244 | 7.5 | 1012.4 | 0.980 | 5.193 | 37.36 | 47.67 |
| 06.10.2019 | 6.0 | 1.268 | 5.0 | 1021.3 | 2.122 | 8.073 | 54.98 | 59.44 |
| 07.10.2019 | 6.5 | 1.264 | 7.2 | 1020.2 | 1.961 | 7.693 | 52.86 | 58.02 |
| 08.10.2019 | 5.9 | 1.259 | 10.1 | 1013.6 | 1.831 | 6.993 | 51.06 | 55.32 |
| 09.10.2019 | 10.5 | 1.225 | 12.5 | 1003.5 | 0.122 | 2.632 | 13.16 | 33.94 |
| 10.10.2019 | 10.9 | 1.225 | 11.3 | 1004.2 | 0.051 | 2.676 | 8.52 | 34.22 |

From the obtained results it can be concluded that with gravitational ventilation it is very difficult to achieve the normative required flow of ventilation air. On 10.10.2019, the ventilation air flow was only 8.52 $m^3$/h, for the kitchen located on the fourth floor, which with the required 70 $m^3$/h is only 12% of the required level.

The situation was no better in a flat located on the ground floor, there the stream was 34.22 $m^3$/h, i.e. 49% of the required value.

Atmospheric pressure also plays a role. At low atmospheric pressure the decrease in the intensity of air exchange is clearly visible.

It would seem that in winter the problem with incorrect operation of ventilation systems will be marginal. All the more when a strong wind begins to blow outside, which increases the intensity of ventilation. In the first half of December in Koszalin, tests were carried out to determine the effect of wind on the chimney draft in bathrooms with gas water heaters installed. The measurement results are presented in Table 2.

On 07/12/2019, for the first time in a month, a reverse flow was observed in the bathroom room, located on the top floor. In the ground floor bathroom the string was correct. The temperature on this day was close to the temperature on 05.12, where no change in flow direction was observed. The decisive factor was the wind, which blew at an average speed of 17.7 km/h, with gusts of wind almost 60 km/h causing the outside air to be forced through the ventilation duct into the rooms and disturbing the correct air flow.

In the following days the wind did not reduce its speed, and the outside air temperature increased a few degrees. This caused interference in ventilation also in other rooms, both on the first and second floor.

**Table 2.** Total pressure in the bathroom ventilation duct depending on the wind in December 2019

| Date | T [°C] avg. | ρ [kg/m$^3$] | Wind [km/h] | | Pres. s. lev. [HPa] | $\Delta p_c$ [Pa] | |
|---|---|---|---|---|---|---|---|
| | | | Int. | Gust | | fourth floor | ground floor |
| 01.12.2019 | 1.5 | 1.287 | 9.20 | 36.0 | 1020.4 | 0.76 | 5.22 |
| 02.12.2019 | 1.7 | 1.281 | 13.10 | 32.4 | 1016.8 | 0.57 | 4.54 |
| 03.12.2019 | 2.3 | 1.285 | 9.30 | 46.8 | 1020.3 | 0.66 | 5.12 |
| 04.12.2019 | 4.2 | 1.274 | 15.20 | 43.2 | 1020.4 | 0.21 | 3.66 |
| 05.12.2019 | 4.4 | 1.274 | 11.70 | — | 1019.9 | 0.19 | 3.68 |
| 06.12.2019 | 2.2 | 1.273 | 16.40 | 43.2 | 1010.9 | 0.26 | 3.57 |
| 07.12.2019 | 4.5 | 1.249 | 17.70 | 57.6 | 1001.1 | -0.68 | 0.43 |
| 08.12.2019 | 7.0 | 1.241 | 18.90 | 54.0 | 1003.1 | -1.16 | -0.46 |
| 09.12.2019 | 6.8 | 1.232 | 17.10 | 46.8 | 995.1 | -1.46 | -1.65 |
| 10.12.2019 | 5.1 | 1.254 | 18.00 | 54.0 | 1006.1 | -0.56 | 1.15 |
| 11.12.2019 | 1.2 | 1.286 | 13.40 | 39.6 | 1017.8 | 0.74 | 5.25 |
| 12.12.2019 | 0.6 | 1.274 | 13.70 | — | 1005.8 | 0.34 | 3.80 |
| 13.12.2019 | 1.7 | 1.256 | 13.20 | 32.4 | 996.7 | -0.29 | 1.44 |

Figure 4 shows the photo taken on 08.12.2019 in the bathroom room located on the ground floor of the building.

**Fig. 4.** Backward flow of ventilation air from the ventilation sheet in the bathroom on the ground floor

## 4. Interpretation of results

In order to strengthen (or reduce) the chimney draft during wind and to protect against reversal of draft, chimney caps are usually installed at the flue gas outlet. The obligation to use them in zones II and III according to (PN-EN 1991-1-4:2008) imposes a Regulation (Rozporządzenie 2002). The above obligation does not apply to ventilation. The pressure in the chimney base depends on the pressure on the roof and the wind speed in the area of the base (Opaliński & Rabczak 2003). If this speed is small relative to the reference speed, then the pressure difference between the chimney outlet and the apartment can reduce the displacement pressure or reverse the flow direction.

Flue gas receding due to the wind is primarily the result of an unfavourable pressure difference between the zone within the apartment windows and the pressure at the chimney outlet. This situation usually occurs when the wind blows on the corner of the building. On the leeward side, one-third of the length of the building creates the greatest negative pressure, and on the roof, in the area where there are usually chimney flue outlets, the negative pressure is relatively low. The flats on the leeward side are in an under-pressure area that may cause back-flow of flue gases (Żurański 2003.)

The effectiveness of ventilation depends on changing weather conditions. Therefore, it is very difficult to meet the requirements for the required ventilation air flows for living spaces.

It should be remembered that both the gas cooker and the instantaneous gas water heater belong to devices that take air necessary for the combustion process directly from the rooms in which they are installed. In these rooms, proper air exchange is of particular importance. In addition to the air necessary for hygiene and sanitary purposes, an additional amount of air necessary for the combustion process must be supplied.

If, when burning natural gas, the amount of air supplied is less than required, then harmful substances will appear next to carbon dioxide in combustion products. The more oxygen there will be, the less oxygen will be available during the combustion reaction.

### 4.1. Theoretical calculations

How important this task is, we can prove by calculating the amount of air that should be delivered to the gas water heater, which has average nominal power of 20 kW.

High-methane natural gas (E) consists in 97-98% of methane ($CH_4$). Other compounds, which are present in the natural gas in small amounts, for example propane, butane, carbon dioxide are of minor importance and to simplify they will be omitted from our considerations.

It requires a simple stoichiometric calculation to discover that for the combustion of 1 $m^3$ of gas (Shkarovskiy & Maliszewska 2018), the required amount of fresh air is 9.52 $m^3$.

Assuming that the amount of air that must be delivered to the device must be increased by 15%, (the excess-air ratio $\lambda$ = 1.15), the actual volume of air delivered to burn 1 $m^3$ methane is equal:

$$9.52 \times 1.15 = 10.95 \text{ m}^3.$$

Assuming that the average calorific power of the gas is 10.35 kWh/$m^3$, and the efficiency of the burner amounts to 70-75%, can be determined the amount of gas, which has to be delivered to the water heater within one hour:

$$Q = 20.0 / (10.35 \times 0.74) = 2.57 \text{ m}^3/\text{ h}.$$

The quantity of air consumed by a water heater is equal:

$$2.57 \times 10.95 = 28.18 \text{ m}^3/\text{h}.$$

This is the required amount of fresh air, which has to be delivered in one hour to the gas water heater in the bathroom to enable it to function properly. This is the amount of air that must be additionally supplied, regardless of the air necessary for hygienic and sanitary purposes.

If the supplied amount of air is less than required when burning natural gas, a negative pressure will be created in the room and the air flow in the ventilation ducts will be reversed.

Improper operation of gas devices for the flow preparation of hot utility water, drawing combustion air from the room is the main cause of poisoning with carbon monoxide in residential premises. A drastic example is the reverse of the draft in the flue gas and the exhaust gas escaping into the room. Lack of adequate supply of air from the outside disrupts the operation of the gas heater.

During the combustion of gas in gas burners, numerous by-products are formed, the most important of which may be nitrogen oxides ($NO_x$) and carbon monoxide (CO).

Reversing airflow can be very dangerous. Polluted air along with harmful compounds is sucked in from ventilation ducts and re-introduced into the rooms. In addition, malfunctioning ventilation does not discharge gases (combustion products) that significantly affect human health. The following calculations will allow you to estimate the scale of the threat.

The flow of gas characterized by a calorific value of 37.60 MJ/$m^3$ with both burners (with a nominal power of 2.00 kW and 2.90 kW) operating simultaneously will be:

$$(2.00 + 2.9) \times 10^{-3}/37.60 \times 3600 = 0.469 \text{ m}^3/\text{h}$$

The expected flue gas stream entering rooms (at the theoretical unit volume of dry basis combustion products, which is 8.52 $m^3/m^3$) (Shkarovskiy & Maliszewska 2018), and taking into account that the standard 200 mg/$m^3$ is converted into $\alpha = 1$, will amount to:

$$0.469 \times 8.52 = 3.996 \text{ m}^3/\text{h}$$

In this way, the amount of nitrogen oxides going into the rooms of the kitchen can be equal:

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

Assuming that the air exchange stream for a kitchen room with a window equipped with a gas stove will be 38 $m^3$/h (data from 03.10.2019), then the possible concentration of $NO_x$ directly in the kitchen room will be (Maliszewska et al. 2019):

$$799.2/38 = 21.03 \text{ mg/m}^3$$

It is a value that significantly exceeds the permissible standards for the concentration of nitrogen oxides even for the working environment (Zarządzenie 1996, Rozporządzenie 2018) which undoubtedly affects the health of people staying in the room.

## 5. Conclusion

1. The efficiency of air exchange, and thus the concentration of harmful substances in rooms, largely depends on changing weather conditions – i.e. outdoor air temperature, atmospheric pressure, wind strength and direction.
2. It is very difficult to achieve the normative required ventilation air flow with gravitational ventilation. In adverse weather conditions it can be as low as a few percent of the required level or reach zero values.
3. Abnormal operation of the ventilation system has already been observed at temperatures less than 10°C, especially in rooms located on the top floor.
4. If during the combustion of natural gas the amount of air supplied is less than required, a negative pressure will be created in the room and the air flow in the ventilation ducts will be reversed, ventilation will not be able to discharge combustion products whose concentration in the room can significantly exceed the permissible standards.
5. Inverted gravitational draft can be very dangerous. Exhaust gas escaping from flue pipes may be sucked in and injected into the building, posing a risk to health and life.
6. The aim should be to install devices with closed combustion chamber in bathrooms where there is a risk of back draft.
7. Distribution of pressure factor values on walls and roof slopes given in the wind impact standards relate to the load on buildings and their elements. It is planned to extend the experimental research related to this issue to adapt it to the needs of ventilation.

8. Chimney cowls mounted on flue gas ducts with low wind may additionally reduce chimney draft, creating additional resistance.
9. In the literature, there is no data relating to changes in the temperature gradient in the exhaust gas flue. It is planned to expand the research related to this issue.
10. It is planned to supplement the experimental research with the analysis of data obtained with the help of programs for numerical modelling of CFD flow. Pre-construction tests could verify the relative location of buildings and help prevent unfortunate accidents due to poisoning.

## References


Jensen, M., Franck, N. (1965). Model-Scale Tests in Turbulent Wind, art II, Wind Loads on Buildings, *The Danish Technical Press, Copenhagen.*

Larsen, T.S. (2006). *Natural Ventilation Driven by Wind and Temperature Difference*. PhD Thesis defended public at Aalborg University 020206.

Maliszewska, A., Shkarovskiy, A. Chernykh, A. (2019). Normative Problems of the Nitrogen Oxides Concentration Limiting in the Human Residence Environment*, Rocznik Ochrona Środowiska, 21, 1328-1342.*

Opaliński, S., Rabczak, S. (2003). *Wentylacja grawitacyjna*. Oficyna Wydawnicza Politechniki Rzeszowskiej.

Polska Norma PN-83/B-03430+A3:2000. Wentylacja w budynkach mieszkalnych, zamieszkania zbiorowego i użyteczności publicznej. Wymagania.

Polska Norma PN-B-10425:1989 Przewody dymowe, spalinowe i wentylacyjne murowane z cegły. Wymagania techniczne i badania przy odbiorze

Polska Norma PN-EN 1991-1-4:2008 Eurokod 1. Oddziaływania na konstrukcje. Część 1-4: Oddziaływania ogólne – Oddziaływania wiatru

Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 r. w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz. U. nr 75, poz. 690 z późn. Zmianami).

Rozporządzenie Ministra Rodziny, Pracy i Polityki Społecznej z dnia 12 czerwca 2018 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy.

Shkarovskiy, A., Maliszewska, A. (2018). Study of air pollution with combustion products of gas stoves in gas-supplied apartments. *Architecture and Engineering, 3(1), 38-43.*

Szkolenie seminaryjne polskiego zrzeszenia inżynierów i techników sanitarnych oddział w Katowicach, (2014). Wentylacja naturalna i mechaniczna warunkiem poprawnego użytkowania obiektów kubaturowych. Katowice: PziTS.

Zarządzenie Ministra Zdrowia i Opieki Społecznej z dnia 12 marca 1996 r. w sprawie dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia, wydzielanych przez materiały budowlane, urządzenia i elementy wyposażenia w pomieszczeniach przeznaczonych na pobyt ludzi.

Żurański, J.A. (2003). *Wentylacja naturalna mieszkań z paleniskami gazowymi a śmiertelne zatrucia tlenkiem węgla*. Forum Wentylacja 2003. Materiały Seminaryjne. Stowarzyszenie Polska Wentylacja, 50-60.
Żurański, J.A. (2016). Wpływ wiatru na wentylację i odprowadzenie spalin gazu z mieszkań. *Inżynier Budownictwa – Materiały i technologie*.

## Abstract

Contemporary systems for removing flue gases and used air should be selected so that there is no risk of accumulation of hazardous and harmful substances in human health. We spend a large part of our lives in our apartments and even relatively low concentrations of harmful substances, that arise during the operation of gas appliances can pose a serious threat to health. The efficiency of air exchange, and thus the concentration of harmful substances in rooms, largely depends on many variables, whose interaction generates a large number of variants. The author of the article set themselves the task of examining the impact of weather conditions on the operation of flue gas exhaust systems and ventilation in rooms with gas appliances.

**Keywords:**
flue gas discharge system, ventilation, chimney draft, wind, indoor gas appliances, air quality

# Wpływ warunków atmosferycznych na działanie systemu odprowadzenia spalin i wentylacji grawitacyjnej w pomieszczeniach z urządzeniami gazowymi

## Streszczenie:

Współczesne systemy odprowadzania spalin i zużytego powietrza powinny być tak dobrane, aby w pomieszczeniach nie powstawało ryzyko gromadzenia się substancji niebezpiecznych i szkodliwych dla ludzkiego zdrowia. W mieszkaniach spędzamy znaczną część swojego życia i nawet stosunkowo niskie stężenia substancji szkodliwych, powstające podczas eksploatacji urządzeń gazowych, stanowić mogą poważne zagrożenie dla zdrowia. Skuteczność wymiany powietrza, a tym samym stężenie szkodliwych substancji w pomieszczeniach w dużej mierze uzależnione jest od wielu zmiennych, których wzajemna interakcja generuje znaczną liczbę wariantów. Autor artykułu postawił sobie za zadanie zbadanie wpływu warunków atmosferycznych na pracę systemów odprowadzenia spalin i działania wentylacji w pomieszczeniach z urządzeniami gazowymi.

**Słowa kluczowe:**
system odprowadzenia spalin, wentylacja, ciąg kominowy, wiatr, urządzenia gazowe w pomieszczeniach, jakość powietrza