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APPLICATION OF CFD FOR INTERIOR FLOW ANALYSIS INFLUENCED BY EXTERIOR CONDITIONS

Метою роботи є ознайомлення із застосуванням CFD-аналізів для внутрішніх потоків у димоходах і квартирах будівель. Наведено короткий огляд тематичного дослідження летальної інтоксикації оксидом вуглецю, що надходить з газового нагрівача проточної води у ванній кімнаті. Такі аварії відбувається переважно через проблеми з вентиляцією і дуже поширені при встановленні газових водонагрівачів у старих будівлях. Закриті герметичні вікна є основними причинами накопичення оксид вуглецю, а іноді неправильна конструкція димоходу та виведення димоходів над конструкцією даху спричиняють зворотну тягу продуктів згоряння. У статті розглянуто нещасний випадок, в одному з польських міст. Газовий нагрівач проточної води, встановленої у ванній кімнаті на першому поверсі, був підключений до трубопроводу з низькорозташованим виходом. Під час вітряної погоди в кінці жовтня один з мешканців квартири помер у ванній через інтоксикацію чадним газом.

Проведені дослідження показали різні порушення в конструкції димаря, а також неправильне розташування вихідного отвору димоходу відносно покрівлі даху. Пояснити причини аварії стало можливо завдяки числовим розрахункам з використанням методів обчислювальної гідродинаміки. Різні форми випускного отвору димоходу було взято до уваги під час аналізу. Було створено тривимірну модель будівлі і квартир. Такого роду моделювання дало можливість з'’ясувати причину аварії.

Ключові слова: вітер, вентиляція, потік у димоході, оксид вуглецю, фатальне сп'яніння.

The aim of the paper is the presentation of application CFD analisys for interior flows in chimneys and flats in a building. It is a summary of a case study of fatal intoxication by carbon monoxide coming from a gas heater of flowing water at a bathroom. That kind of accidents mostly happens due to problems with ventilation and very popular old construction gas water heaters. Closed, airtight windows are the main causes of the production of carbon monoxide but sometimes wrong construction of the chimney outlets versus the roof shape causes the backdraught of combustion products. The paper deals with an accident which took place in one of Polish cities. Gas heater of flowing water installed in a bathroom at the first floor was connected to the vent pipe with a low outlet. During windy weather conditions, at the end of October, so in a cold season, one of the inhabitants of the apartment died in bathroom due to carbon monoxide intoxication.

An investigation has been carried out, which has shown various irregularities in the construction of the chimney, as well as misuse of the outlet. Explanation of the causes of the accident was possible thanks to the numerical calculations using CFD methods, the scope and extent of which is presented in the paper. Different shapes of chimney outlet were taken into consideration during the analysis. Three dimensional model of a building and flats was created. That kind of simulations gives the possibility to find out the reason of the accident.

Key words: wind, ventilation, flow in a chimney, carbon monoxide, fatal intoxication

Introduction. In one of the Polish cities a new building was constructed among the old ones. The building has been covered with an arched roof of 15 m span. The roof exceeds the adjacent flat roofs in height by 6 m.

The new roof has changed the aerodynamic characteristics of the neighboring buildings, especially around the chimney outlets of the ventilation and exhaust ducts. Some of the chimneys' heights have been changed to fulfill the requirements of the Polish Standard (PN-89/B-10425).

Fig. 1. The view of the new building from the street and of the outlets after adjustments

Other outlets' heights have not been changed because they were located further than 10 m from the top of the roof, thus they were outside the distance given in the Standard. One of the outlets remaining at its primary height was originally an outlet of the ventilation duct and to this vent duct a flowing water gas heater was connected in an apartment at the second floor. Consequently, the outlet's function was changed to an exhaust duct outlet. However, the construction of the chimney remained untouched, the chimney had two side wall outlets left as designed for a ventilation duct outlet.

After a few years, during autumn and windy weather conditions, one of the inhabitants of the apartment died due to carbon monoxide intoxication. An investigation has been conducted and has shown various irregularities in the construction of the chimney, as well as a misuse of the outlet. Nevertheless, the investigation did not provide any explanation of the cause for carbon monoxide formation and spreading in the bathroom, and in the entire apartment as well. The proven construction irregularities were only of non-compliance with the Standard, in some cases depending mainly on its interpretation. The explanation of true causes to the accident was possible only after numerical calculations which scope is presented in this paper.

Initial conditions. Before the elaboration of an expertise, all essential information needed to be collected. In this case, required data include conditions from the moment of the accident inside the apartment, as well as on the outside, including the shape of the building and meteorological conditions, which can play crucial and sometimes decisive role.

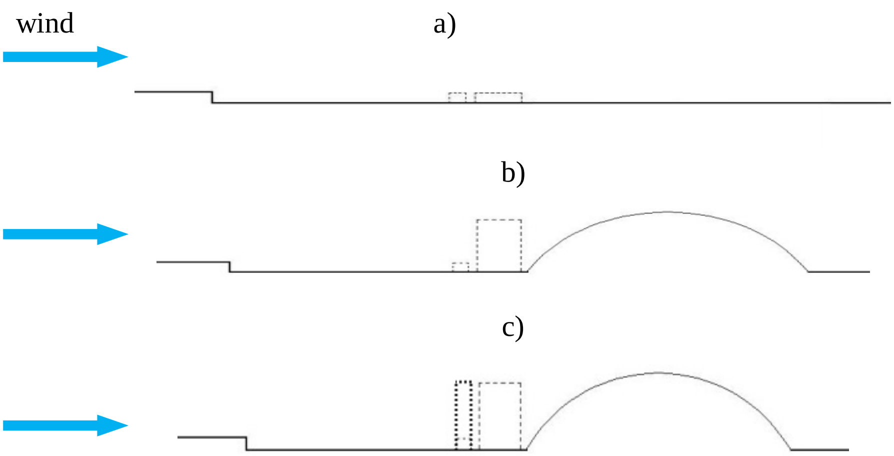

Fig. 2. A cross-section of the roofs: a – before the construction of the arched roof;
b – after the construction and c – the height of a chimney as recommended. Wind direction is marked

The initial conditions, the wind speed and direction at the time of the accident were retrieved from the measurements from the nearest weather station that was located at the airport. The 10-minute mean wind speed at a height of 13 m above the ground was 11 m/s, gusting up to 19 m/s and ambient air temperature was 9 ^{o}C (Krajewski and Zuranski, 2009).

The wind speed has been modeled according to the power law with an exponent of 0.19 for wooded terrain at the meteorological station windward of the anemometer for the wind direction that was taken into consideration, that is a category B according to (PN-77/B-02011) and 0.24 for a city (category C). Gradient heights were assumed at 400 m and 500 m, respectively.

Based on mentioned assumptions the wind speed profile was estimated. Only 10-minute mean wind speed were used in the calculations. It was app 10 m/s at the height of chimney outlets.

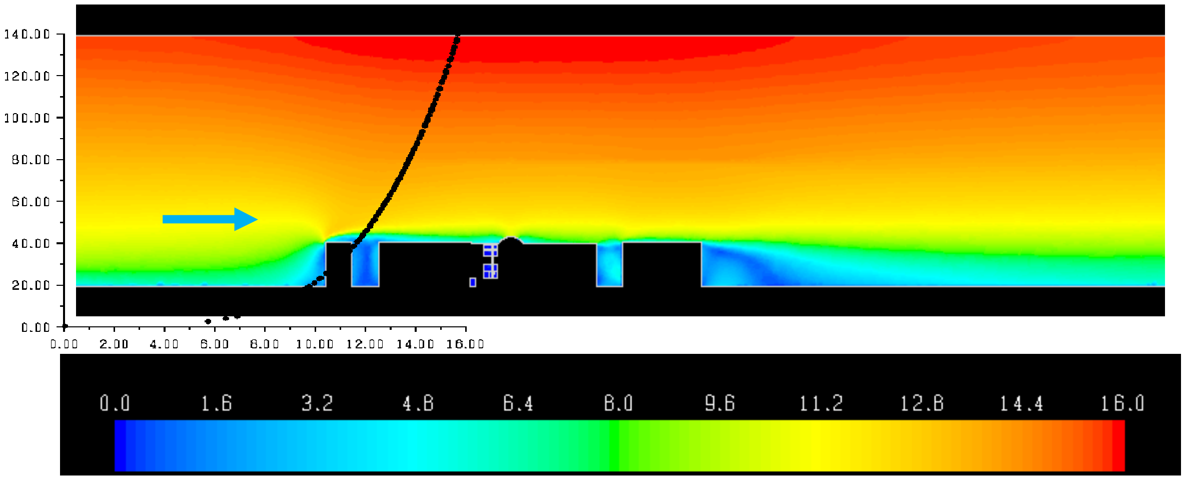

Fig. 3. The area included in the analysis. Underneath, the wind speed scale and left the mean wind speed profile are presented

The three-dimensional model of the analyzed domain was based on the architectural plans of the building, including chimneys, and a testimony of eye-witnesses. Based on information from on-site inspection and prosecution files, an assumption was derived that all the windows were closed apart from the one in the kitchen that was slightly repealed. This assumption could not be verified.

Several other flats, connected with the one previously taken into consideration, have also been modeled. All modeled flats form a complex of buildings are enclosed by three streets and a courtyard.

The simulation also takes into account the leakage through the door to the staircase and to other apartments, as well as leaks through the attic windows.

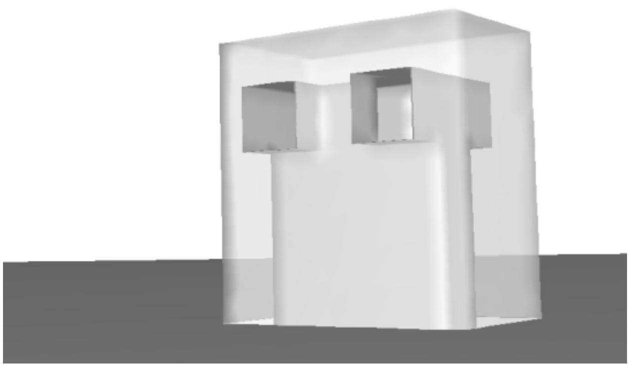

Fig. 4. The view of the outlet of the chimney during the accident. Wind direction was parallel to the walls with the outlets

Subjected to a particularly detailed analysis were: the part of the roof surrounding the chimney with the exhaust duct outlet connected to the flow gas water heater and the area around the connection of the gas heater to the chimney with a small fan installed at a side of the ventilation duct.

The chimney protruded over the roof surface by about 0.6 m, the centers of the two outlets were at 0.4 m above the roof surface.

Calculation. In order to evaluate the effectiveness of the existing exhaust installation a series of calculations was made using Computational Fluid Dynamics. The calculations have been conducted using ANSYS Fluent software which has been strongly validated in numerous branches of science in various scientific institutions, including the Building Research Institute in Warsaw, Poland.

The three-dimensional analyzed domain has been divided using a tetrahedral grid of 7 400 000 elements with dimensions, ranging from 25 mm in the area of a chimney outlet to 1.0 m on peripheries of the domain.

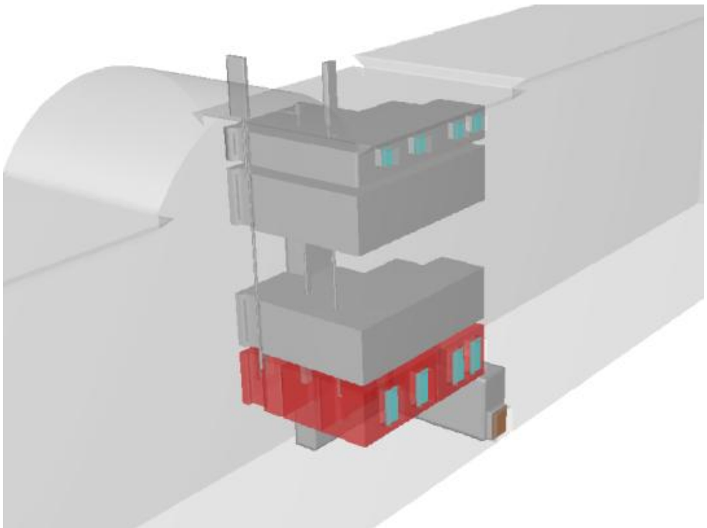

Fig. 5. Three-dimensional model of the analyzed building

Conducted simulations were transient. RANS k-ε turbulence model was applied in the calculations. Various situations have been investigated: the presence and absence of the new roof, varied heights of chimney outlets and changes in the chimney outlet and in the flat. Only one wind speed and its direction has been taken into consideration, as observed during the accident. Indoor air temperature was assumed at 20 ^{o}C and the temperature of combustion products at the outlet of the gas heater was 180 ^{o}C. Thus the buoyancy effects and gravity forces have been taken into calculations.

The analyzed area has been divided into a finite number of control volumes using an unstructured tetrahedral numeric grid. Total number of control volumes was approximately 7 400 000. In the vicinity of slits and in places where large gradients were expected the local density of the mesh was increased.

The calculations were conducted using the turbulence model Realizable k-ε. Additionally, in order to recreate the conditions in the apartment, as accurately as possible, heat sources imitating the burner in the gas water heater were implemented into the model.

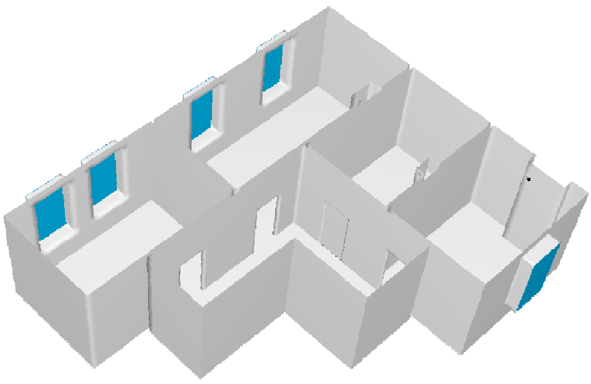

Fig. 6. Digital model of the analyzed flat

Results. After conducting the analysis the following conclusions were reached. First of all, resulting from the existing construction, features of the chimney; as well as the external conditions during the accident, in the initial phase of the water heater operation the products of combustion were not discharged upwards through the chimney but returned into the bathroom through the small fan outlet of the former ventilation duct above the place where the exhaust pipe was connected to the ventilation duct (Fig. 8).

The calculations assumed that the small fan did not function at the time. If the side wall outlet fan was removed from the model, still a similar effect of discharge of exhaust into the bathroom occurred, only the fumes would flow through the inside of the heater.

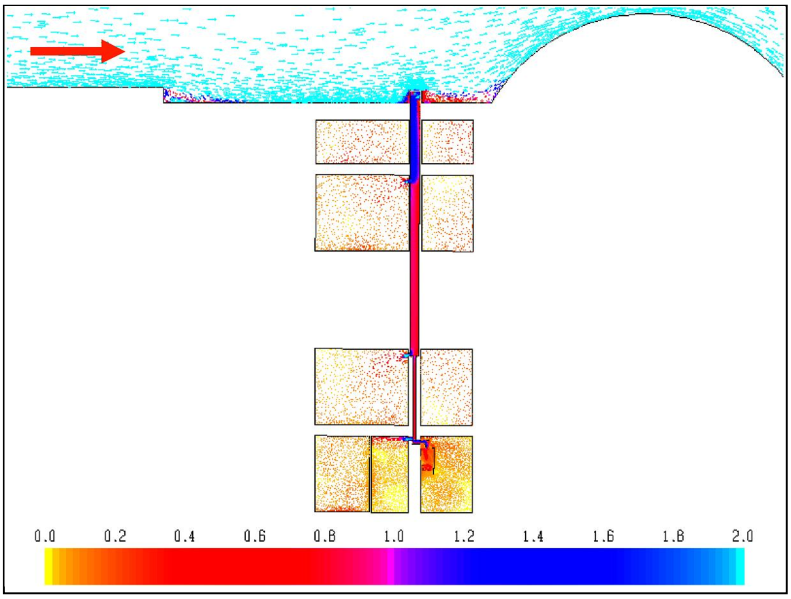

Fig. 7. Exhaust chimney duct and the connected rooms

The discharge of fumes was blocked by the cold air from the outside in the long chimney duct. The flow in the chimney was reversed due to the influence of the wind. Higher chimneys that served for the ventilation of the same apartment had outlets in the area of higher wind speed because the outlets were higher and closer to the arched roof.

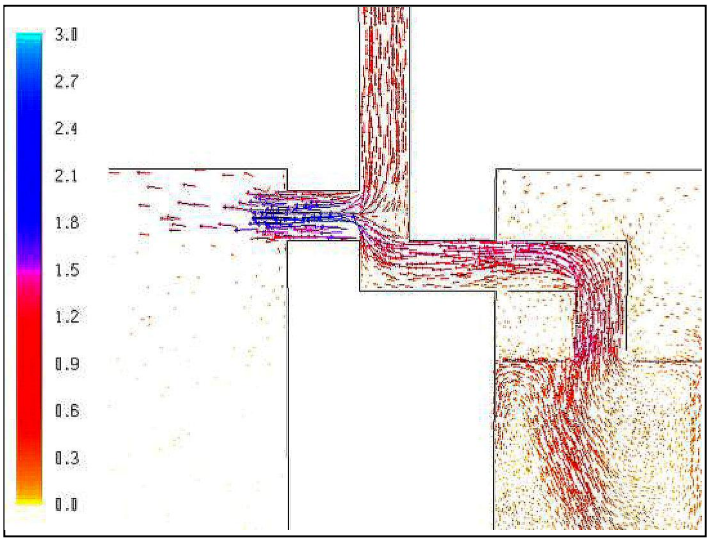

Fig. 8. Wind speed vectors in the cross-section of the chimney near the connection of the gas heater

The backflow of fumes in the chimney also occurred after the heater had been turned off. Switching the heater on an off several times in the condition of the oxygen deficiency in a flat, led to the gradual increase of fumes and carbon monoxide concentration in the bathroom and in the entire apartment, and in the end to a fatal accident. There were 6 persons slept in the apartment at the night before the accident and the deceased has been the last person to use the bathroom in the morning.

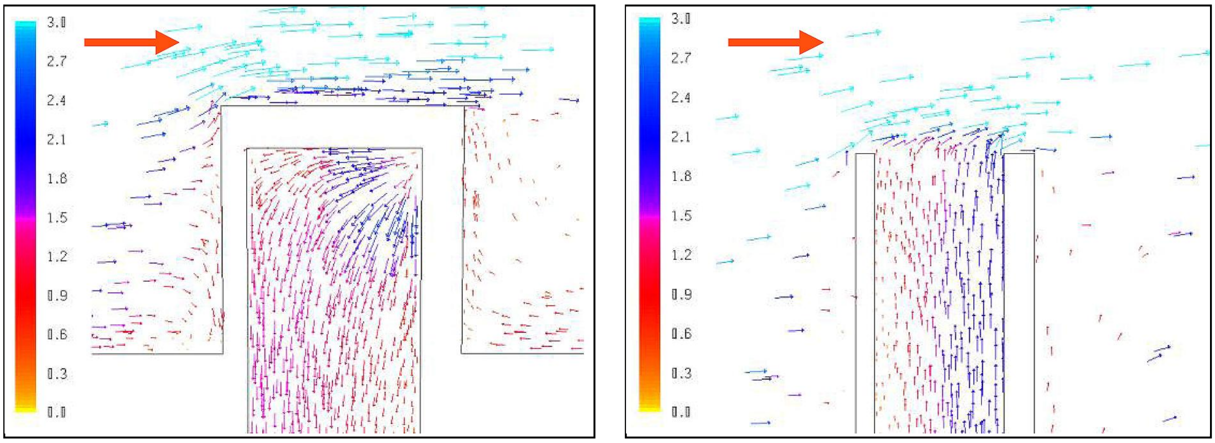

Fig. 9. Wind speed vectors in the cross-section of the chimney near the chimney outlet. Left: the existing construction; right: the recommended construction of the chimney. Wind direction is matked by an arrow

The problem of the cold air influx from the outside to the chimney can be eliminated by increasing its height to the similar height of all the other chimneys, as well as moving the outlet of the duct to the top of the chimney from the side walls (Fig. 9). The last improvement has been implemented in compliance with the Polish Standard (PN-89/B-10425).

Conclusion. Based on the conducted analysis and calculations the importance of chimney height and placement of chimney outlets for functioning of a ventilation system was proven.

The investigation has also shown the negative effects of the unsupervised changes made by inhabitants of the apartment on the functioning of natural ventilation of the apartments. Such actions can often lead to accidents with fatal results.

Combained analisys of interior flows, thermal exchange and computational wind engineering made it possible to explain the causes of fatal intoxication by carbon monoxide in a dwelling. This combination of methods can be used in many branches of engineering for example in fire safety enginnering with natural ventilation. Global view for a problem is one of the most important thing to check and prove the environmental parameters.

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