

CFD Modelling of Indoor Environment Quality Affected by Gas Stoves

László Kajtár and Anita Leitner

Budapest University of Technology and Economics, Hungary

Corresponding author email: kajtar@epgep.bme.hu

SUMMARY

Gaseous emission - CO₂, NO, and NO_x of gas stove has significant and harmful effect on indoor air quality (IAQ) in residential kitchens. To avoid increasing health risk it is essential to use mechanical ventilation such as kitchen hood. However, according former laboratory studies, extract air flow generated by typical hoods is not adequate to achieve required IAQ. Thus there is an increasing need to develop a new kitchen ventilation system and to estimate the required exhaust ventilation rate.

In order to describe required ventilation of kitchens, emission of gas stoves has been investigated for years at Department of Building Service Engineering, BUTE. Laboratory and field studies were carried out, afterwards, based on the results, pollutant distribution was described by CFD simulation (FLOVENT).

In this paper an overview of method and results of CFD modelling is published.

INTRODUCTION

Gas stoves as pollutant sources can be described in accordance the power of burners. However occupants' behaviour (the way of use) takes significant part as well. If gas stoves are used in order to reduce required heat load of boiler, burner will run free. In this case pollutant concentration could be increase by 200-300%. From health point of view it should be taken into consideration that occupants normally stand near to the source during the cooking. Thus air in breathing zone contains higher level of pollutants. Therefore occupants are primary affected by combustion products. Application of hoods decreased the concentration levels but it has not appeared to be satisfactory in IAQ point of view.

In case of gas stoves Hungarian standards has a main issue providing fresh air to ensure burning process and to defend human health. However indoor air quality has an increasing impact on design process.

In order to help design, implementation and maintenance to develop more effective kitchen ventilation system, effect of gas stoves has been studied at laboratory and field studies. Based on results it is proved that trade hoods ($V_{ex,max} = 180 - 250 \text{ m}^3/\text{h}$) can not ensure the required ventilation from IAQ point of view.

To estimate required exhaust air flow CFD modelling has been made by FLOVENT. Number of cases has been investigated as regards amount of air removed by kitchen hood. Supply air has been provided using air terminal devices installed above the windows. Validity of CFD model has been investigated based on results of former laboratory and field studies.

METHODS

Using CFD modelling it can be predicted air moving in the enclosure. Calculations are based on fundamental flow and energy equations such as:

- Navier – Stokes equations
- Energy conservation
- Mass conservation
- Concentration equations
- $k - \epsilon$ turbulence model

To solve these it is necessary to make modelling assumptions in order to describe the investigated phenomenon in an accurate way. This also helps to decrease number of parameters, required computer capacity and solution time. Main modelling assumptions are follows:

- outdoor air does not contain any of pollutants;
- supply air temperature is equal to outdoor air temperature;
- invariant outdoor climatic circumstances (air temperature, air velocity, pressure);
- continuous ventilation by given amount of ventilated air.

Geometrical model has developed according architectural parameters of enclosure investigated at field studies. Gas stove model has been made following proportions of a device with average technical parameters, therefore commonly used one.

Pollution loads have been estimated by laboratory measurements. Considered operating time: 60 minutes. Initial indoor air temperature $t_i(\tau=0) = 20^\circ\text{C}$.

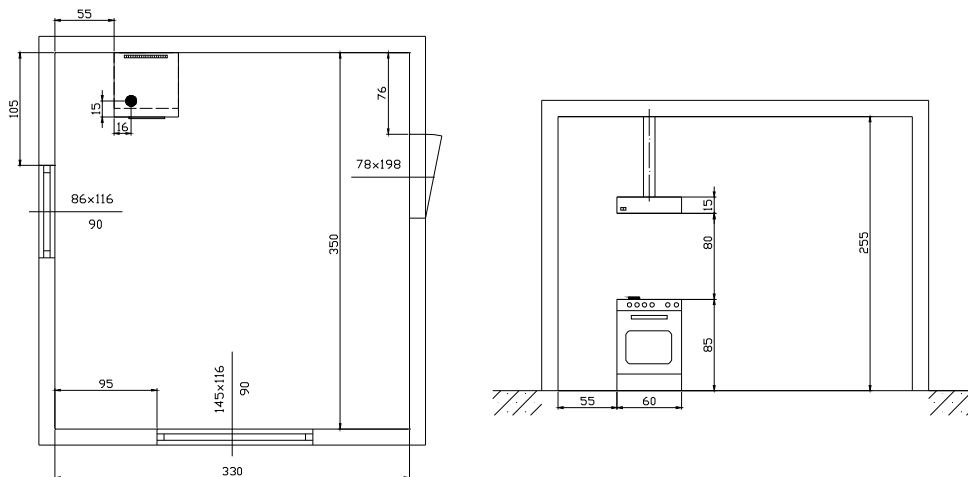


Figure 1. Plan of model kitchen ($V_h = 29,5 \text{ m}^3$)

Table 1. Investigated kitchen ventilation systems

Burner power $P=5\text{kW}$		
Air flow extracted by hood ($h=80 \text{ cm}$)	Supply air terminal device	Pollution load
$0 \text{ m}^3/\text{h}$	-	$G_{\text{CO}_2} = 1,80 \cdot 10^{-4} \text{ kg/s}$ $G_{\text{NO}_2} = 2,48 \cdot 10^{-8} \text{ kg/s}$ $G_{\text{NO}} = 7,80 \cdot 10^{-8} \text{ kg/s}$
$60 \text{ m}^3/\text{h}$	1 x $60 \text{ m}^3/\text{h}$	
$180 \text{ m}^3/\text{h}$	2 x $90 \text{ m}^3/\text{h}$	
$250 \text{ m}^3/\text{h}$	2 x $125 \text{ m}^3/\text{h}$	
$500 \text{ m}^3/\text{h}$	4 x $125 \text{ m}^3/\text{h}$	

Thermal properties of stove have been studied in laboratory measurements as well, by measuring air temperature changing around the working stove at 10 points. At the same time surface temperature at different parts of stove envelope has been measured too.

To describe effect of increasing surface temperature approximate functions have been developed based on measurements' results.

Burner has been model by a heat source element with same heat exchanger area as the real one. Pollutant source have been placed above to the "burner". Three sources have been used for main gaseous products of burning: carbon-dioxide (CO₂), nitrogen-oxide (NO) and nitrogen-dioxide (NO₂).

For any sort of contaminant initial concentration is zero ($k_b(\tau=0)=0$ ppm). Outdoor air has been taken into consideration as clean air.

Modelling grid is a main issue as regards accuracy of model. It is highly recommended to avoid any over dimensioning or using too poor grid system. In order to provide a proper solution at lower need of computer capacity, different regions have been worked up in the CFD model. In regions with high expected concentration, temperature or velocity gradients fine grid has been applied.

Seven regions have been defined with different grid:

1. Burning area (above top plate of stove)
2. Extract area (beside under plate of hood; extracting zone)
3. Front area (beside front plate of stove; primary occupied zone)
4. Left area (left side of stove; secondary occupied zone)
5. Right area (right side of stove; secondary occupied zone)
6. Envelope area (around the stove, along the surface of envelope)
7. Wall area (along inside surface of walls)

Total grid system of the model are contain 72 528 cells.

To describe time depending parameters time-step(s) has to be estimated. Total transient period (60min) has been divided into following steps: 2min, 5min, 10min, 15min, 20min, 30min, 45min and 60min. Data saved at 10th, 30th and 60th minutes.

Changing of calculated parameters (concentration, temperature and air velocity) has been followed at 10 monitor points placed in front of the stove, at 1.5m high along the centreline of the burner, in every 10cm.

RESULTS

Results are presented in table form and by visualisation as well, at above mentioned transient time step. At visualisation investigated areas have been selected according monitor points.

In following Figures results at 30min can be seen, in case of no ventilation and 250 m³/h exhaust air flow.

- CO₂ concentration: Figure 2 a. and b.
- NO concentration: Figure 3 a. and b.
- NO₂ concentration: Figure 4 a. and b.

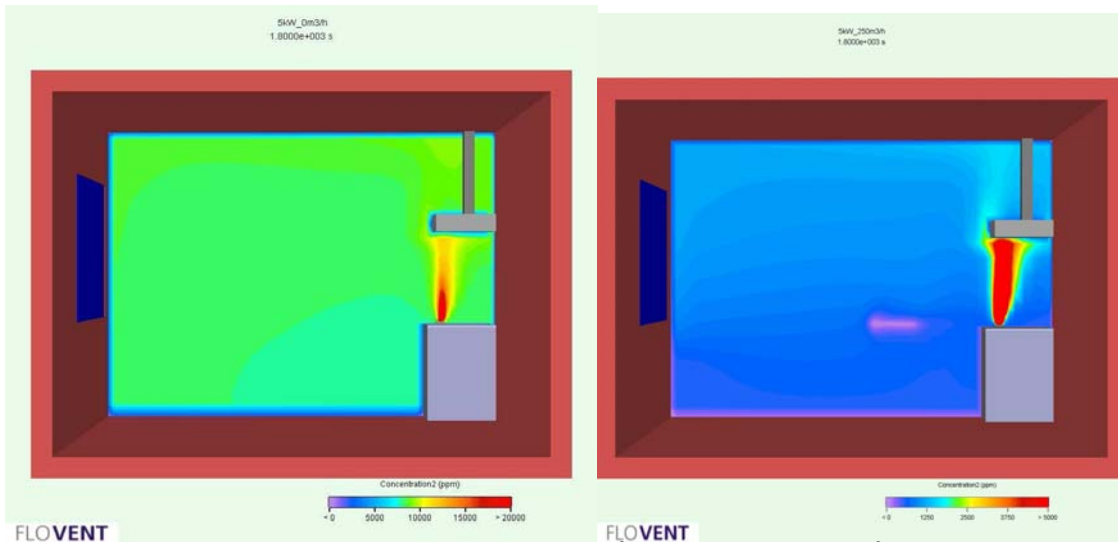


Figure 3. CO₂ concentration (30min) a.) V=0 m³/h b.) V=250 m³/h

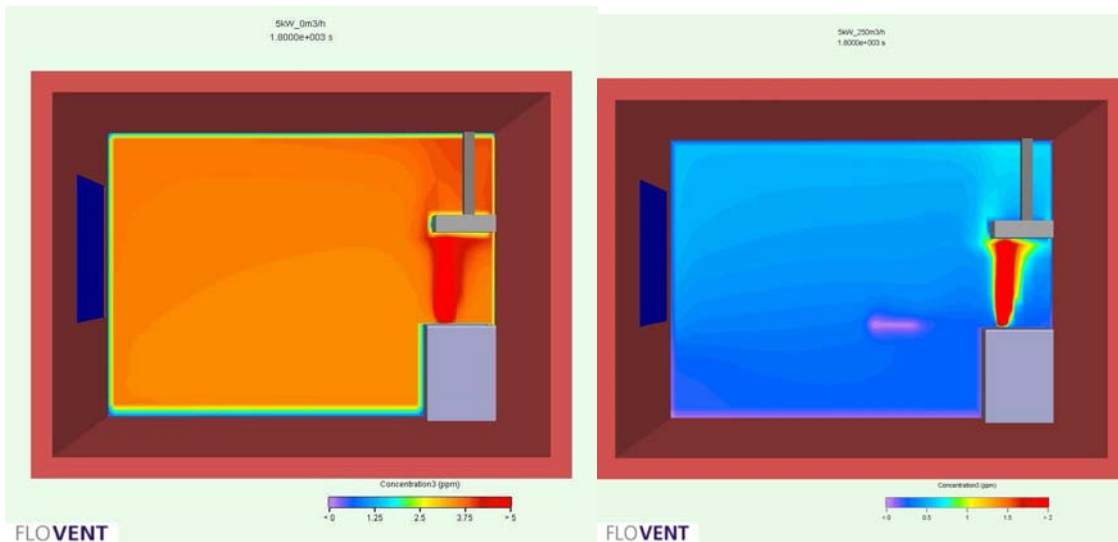


Figure 4. NO concentration (30min) a.) V=0 m³/h b.) V=250 m³/h

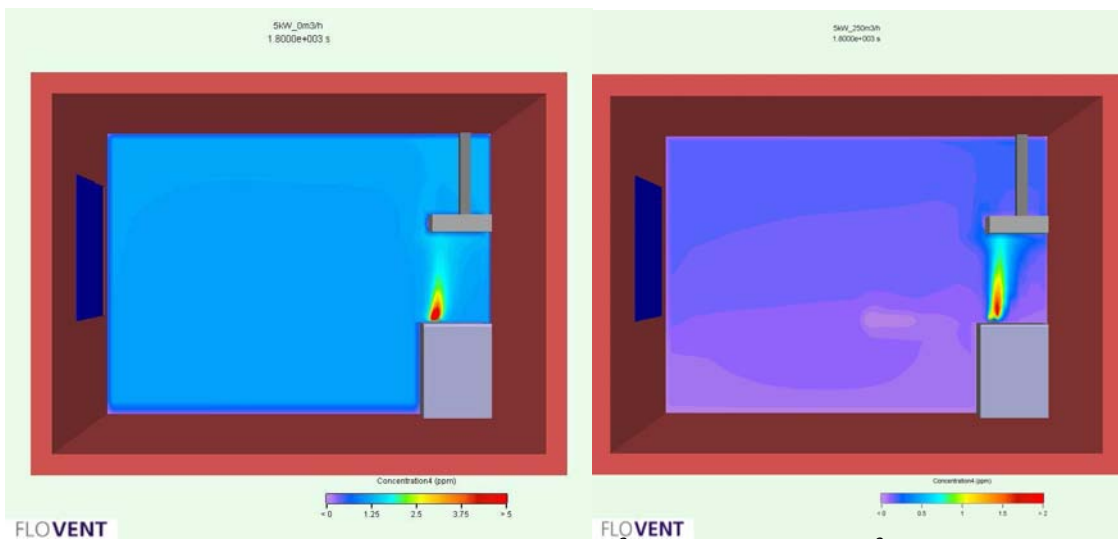


Figure 5. NO₂ concentration (30min) a.) V=0 m³/h b.) V=250 m³/h

CONCLUSIONS

- In kitchens equipped gas stoves it is strongly recommended to install mechanical ventilation system to provide required concentration level of CO₂ and NO_x.
- Using kitchen stoves as heating equipment results significantly decreasing indoor air quality level.
- Kitchen hoods with typical technical parameters ($V_{ex,max} = 180-250 \text{ m}^3/\text{h}$) can not provide Hungarian requirements for NO_x concentration ($200 \mu\text{g}/\text{m}^3$)
- As regards CO₂ concentration required air flow is given in Table 2.

Table 2. Required exhaust air flow

Working period [min]	$V_{ex} [\text{m}^3/\text{h}]$	
	$c_{\text{CO}_2} < 2\,500 \text{ ppm}$	$c_{\text{CO}_2} < 5\,000 \text{ ppm}$
15	65,0	0,0
30	140,0	66,0
60	160,0	92,0

ACKNOWLEDGEMENT

This research has been carried out by a commission of Hungarian Research Fund and Association of Gas Distribution Companies.

REFERENCES

1. Kajtár L.-Leitner A.: Az „A” típusú gázkészülékek elhelyezési feltételeinek modellezése Magyar Épületgépészet, LV. 2006/6. 3-7p.
2. H.B. Awbi: Ventilation of buildings
London. 1998 E & FN Spon
3. Kajtár L.-Leitner A.:Effect of Gas Range upon Air Quality of Living Spaces.
Coimbra, Portugália. 2004. ROOMVENT 2004, 9th International Conference on Air Distribution in Rooms. Book of Abstracts 126-127p. CD 6p.
4. Kajtár L.- Leitner A.: Air Quality of Living Spaces with Gas Range
5thInternational Conference Indoor Climate of Buildings '04 Health, Comfort and Safety by Operation of HVAC – R Systems, 2004. nov. 21-24. Strbske Pleso, Proceeding 155-160 p.
5. Kajtár L.-Bánhidi L.-Leitner L.: Air quality and thermal comfort in kitchens.
Beijing, China, 2005. Sept. 4-9. 10th International Conference on Indoor Air Quality and Climate Proceedings Volume II/2. 2371-2375 p.
6. L.Kajtár – A. Leitner – L. Bánhidi: Evaulation of IAQ in residential kitchens based on laboratory and field studies
Healthy Buildings 2006 Conferece Lissabon 2006.