

# Living quarters. A natural balanced ventilation system. Simulations part 1

Tomasz Gaczol<sup>1,\*</sup>

<sup>1</sup>Cracow University of Technology, Institute of Construction Design, 1 Podchorążych str., Cracow, Poland

**Abstract.** In the following article the author proposes the solution for a properly functioning natural ventilation system based on the use of supply and exhaust ducts, i.e. by designing a natural balanced ventilation system. The paper is devoted to test results of air flow through natural ventilation supply-exhaust ducts in the rooms located on the lower floor of the building. The simulations conducted in ANSYS Fluent software relate to such issues as: pressure system inside the room and in the exhaust duct, distribution of air temperatures in the room, vector direction of airflow through supply-exhaust ducts and in the analysed room. Three types of solutions were selected for the tests: air inflow into the room through the air intake located at the basement level, air inflow through the window ventilator (although no longer used, this solution can be found in many existing residential buildings) and the natural ventilation system supported with the so-called “solar chimney”. All simulations were conducted with an outdoor temperature of +3 degrees C. The indoor temperature is + 20 degrees C, considered to be the minimum thermal comfort level. In the era of common building sealing, the presented ventilation system may be a good solution that guarantees proper functioning of natural ventilation. In all cases presented, it meets the normative regulations and requirements for the ventilation air stream and the air exchange rate in the room. The paper (first part) describes test results concerning the room located on the lower floor of the building, i.e. with a short supply duct and a 12-meter long exhaust duct.

## 1 The choice of topic

Frequently conducted construction works involving thermal modernization of a building limit the inflow of the appropriate air stream to the living quarters. This is the reason for the emerging problems associated with improperly functioning gravity ventilation that operates periodically and with variable efficiency. In the vast majority of cases, existing residential buildings in Poland are created on the basis of a natural ventilation system. In accordance with the requirements of PN-83/B-03430, new structures of up to 9 storeys can also be equipped with a natural ventilation system. In both cases, the proposed solution can have a broad scope of application in our country. It does not require large financial outlays or the use of complex, expensive ventilation devices. Following the example of many world famous construction projects that have been created on the basis of a selected natural ventilation system, it can bring satisfactory results, primarily related to human health and good technical

---

\* Corresponding author: [tgaczol@pk.edu.pl](mailto:tgaczol@pk.edu.pl)

condition of facilities (Cultural Center of Jean Marie Tjibaou – New Caledonia, Comerz Bank in Frankfurt, Contact Theatre in Manchester). The presented solution is a very simple idea that can be used to upgrade existing buildings and design new ones. It does not require large financial outlays and works automatically as it consists in a gravity ventilation system without any support elements. Properly operating natural ventilation conditions the health and well-being of people in the building, as well as good microclimatic parameters, e.g. humidity, temperature or appropriate negative air ionization. An optimum technical condition of the building envelope and other elements of the facility, free from dampness and mould formation, is also dependent on a well-functioning gravity ventilation.

## 2 A natural balanced ventilation system

Gravity ventilation is achieved by connecting the internal volume of the room with the outdoor environment by means of a ventilation duct led above the roof level. The pressure equalization plane is located above the room, so in the entire interior the pressure is lower than the atmospheric one. This type of ventilation is called exhaust natural ventilation [1], [2].

The requirements for the intensity of air exchange in living quarters in Poland (table 1) refer to: man-made pollution and the degree of air humidity. It is assumed that the minimum amount of fresh air per person is 20 m<sup>3</sup>/h. According to current regulations and building standards [3], [4], the intensity of the exchange is the sum of the air masses removed from contaminated rooms such as toilets, bathrooms and kitchens. Neither the size of the apartments nor the number of inhabitants is relevant here. Therefore, the amount of air exchanged per person may vary considerably. As a result of fitting new, tight window and door frames, thermal modernization of buildings, the buildings become sealed and thus the proper functioning of the natural ventilation system is disturbed. This can lead to the appearance of a backdraft in the ventilation ducts, and hence to many unpleasant consequences, including life and health hazard [5].

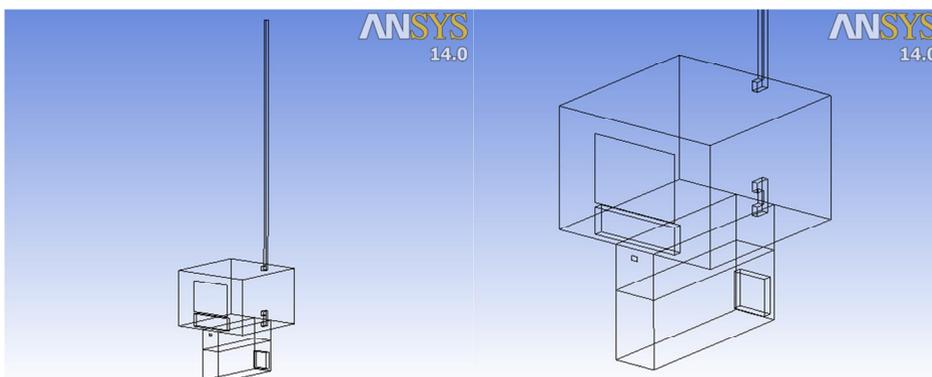
The natural balanced ventilation system guarantees a proper exchange of ventilation air [6]. In the three cases considered, i.e.: air inflow into the room through the air intake located at the basement level, air inflow through the window ventilator (although no longer used, this solution can be found in many existing residential buildings) and supporting the natural ventilation system by the so-called “solar chimney”, an outdoor temperature value was set at +3°C.

**Table 1.** Drawing by the author on the basis of: PN-83/B-03430 (including the amendment A3:2000) „Ventilation in residential, multi-family residential and public buildings. Requirements”.

For a kitchen with an external window, equipped with a gas or coal cooker	70 m <sup>3</sup> /h
For a kitchen with an external window, equipped with an electric cooker - in an apartment for up to 3 persons - in an apartment for more than 3 persons	30 m <sup>3</sup> /h 50 m <sup>3</sup> /h
For a kitchen without an external window or for a kitchenette equipped with an electric cooker	50 m <sup>3</sup> /h
For a bathroom (with or without a toilet)	50 m <sup>3</sup> /h
For a separate toilet	30 m <sup>3</sup> /h
For a living room, located on the top floor of a multi-storey single-family house or in a multi-level apartment of a single-family house	30 m <sup>3</sup> /h
For an auxiliary room without a window	15 m <sup>3</sup> /h
<b>Kitchens without an external window equipped with a gas cooker should have mechanical exhaust ventilation;</b> the removed air stream should be	70 m <sup>3</sup> /h

## 2.1 The first case

The first case presents a living quarter on the ground floor with an area of  $16.0 \text{ m}^2$  and a volume of  $43.2 \text{ m}^3$ , ventilated with natural balanced ventilation ducts with a cross section of  $14 \times 14 \text{ cm}$  ( $196 \text{ cm}^2$ ), enlarged to  $14 \times 21 \text{ cm}$  in the supply part. The air inflow is provided by a duct led from the air intake located in the basement of the building. The air intake is a room with an area of  $4.0 \text{ m}^2$  and a volume of  $10.0 \text{ m}^3$ . Outdoor air at a temperature of  $+3 \text{ }^\circ\text{C}$  flows into the intake through an opening of  $14 \times 14 \text{ cm}$ . The intake room must have finished walls and the floor as washable surfaces that are easy to clean and it should contain a heater, which heats the incoming outdoor air in this case. The temperature of the heater in the air intake is  $+70 \text{ }^\circ\text{C}$ . The heated air is supplied from the intake to the living quarter through a  $60 \text{ cm}$  air duct with a cross section of  $196 \text{ cm}^2$ . In the living quarter located on the ground floor of the building there is a  $210 \times 150 \text{ cm}$  window and a  $210 \times 70 \text{ cm}$  heater with the required temperature of  $+35 \text{ }^\circ\text{C}$  below it. The aforementioned required temperatures of the heaters were chosen so that in each case the indoor room temperature is maintained at  $+20 \text{ }^\circ\text{C}$ , considered to be the minimum thermal comfort level. The window is designed to be tightly closed (no infiltration through window frames). The air is discharged from the ventilated living room to the outside through a  $12.0 \text{ m}$  exhaust duct. The geometry of the examined case is shown in Figure 1.



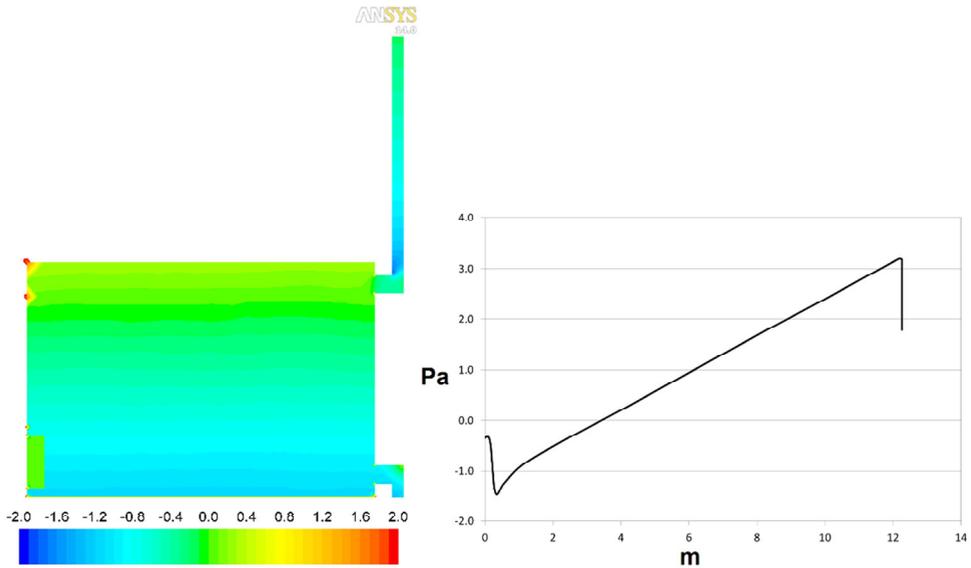
**Fig. 1.** Axonometric drawing of the model. Case 1.

During the computer simulations, the following tests were conducted in Ansys Fluent software: air pressure distribution (the given pressure diagram was measured in Pa) in the living quarter and in the exhaust natural ventilation duct (vertical section of the room and the exhaust natural ventilation duct) – Figure 2.

### Conclusions:

There is an increase in pressure in the upper part of the room clearly visible in the longitudinal section. At the bottom there is a negative pressure, at the top the pressure approximates the pressure outside the room. Initially, there is a noticeable drop in pressure in the exhaust chimney, but it increases as the length of the exhaust chimney increases.

- Vector direction of the airflow (m/s) in the longitudinal section of the room and supply and exhaust ducts as well as in the cross section.



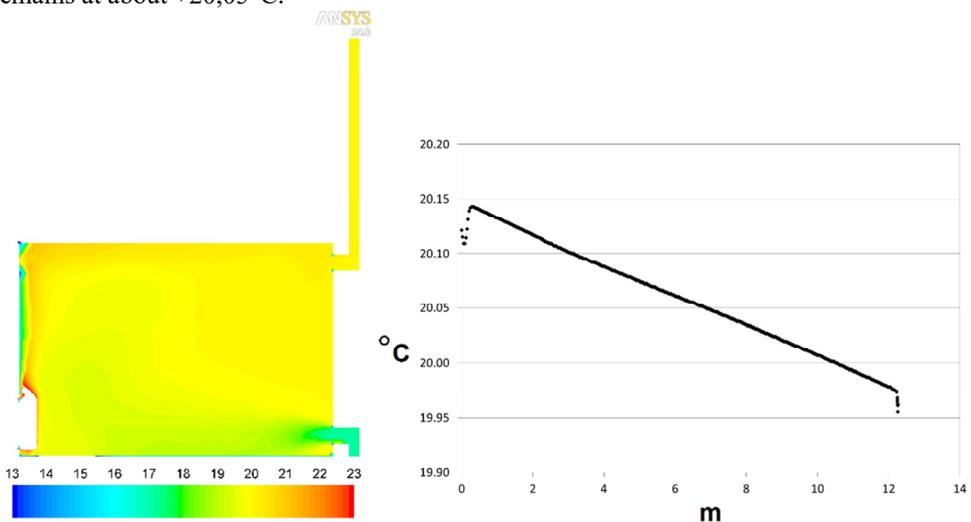
**Fig. 2.** Pressure distribution in the longitudinal section. Diagram showing pressure in the exhaust duct (Pa).

**Conclusions:**

An increased air movement at the level of about 0.8 to 1 m/s can be observed only in the area of air supply and exhaust and near the heater. The air speed inside the room is around 0,3 m/s. The air particles get mixed.

- Distribution of air masses temperature ( $^{\circ}\text{C}$ ) in the longitudinal section and cross section of the living quarter, longitudinal section of the air intake, living quarter and supply and exhaust chimneys as well as the diagram of air temperature in the chimney ( $^{\circ}\text{C}$ ) – Figure 3.

The temperature ranges from  $+16^{\circ}\text{C}$  in the lower part of the room to around  $+22^{\circ}\text{C}$  in the upper part of the room. The average indoor temperature is  $+20^{\circ}\text{C}$ . The air temperature in the exhaust chimney decreases slightly as the length of the chimney increases and remains at about  $+20,05^{\circ}\text{C}$ .

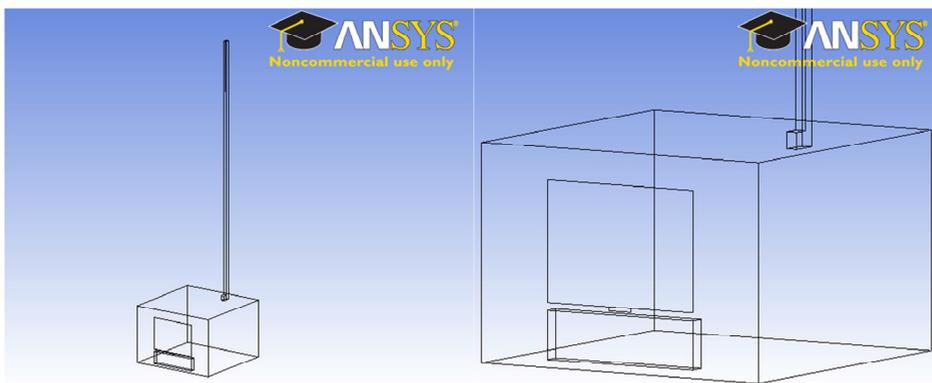


**Fig. 3.** Distribution of air temperatures ( $^{\circ}\text{C}$ ). Distribution of ventilation air temperatures ( $^{\circ}\text{C}$ ) in a 12-metre exhaust duct.

The outdoor air (+3°C) is heated in the air intake up to a temperature of about +14°C, then additionally heated to a temperature of about +16°C, by means of a heater placed in the lower zone, it is supplied through the supply duct to the living quarter. According to computer calculations, the ventilation air stream is 0.0225 kg/s = 67.5 m<sup>3</sup>/h, which accounts for about 1.5 times the air exchange in the room.

## 2.2 The second case

The second case presents a living quarter on the ground floor with an area of 16.0 m<sup>2</sup> and a volume of 43.2 m<sup>3</sup>, ventilated by an exhaust natural ventilation duct with a cross section of 14×14 cm (196 cm<sup>2</sup>), enlarged to 14×21 cm in the supply part. The air inflow is provided by a window ventilator with a cross section of 5×32 cm, which allows the outdoor air at a temperature of +3°C to flow in. This type of ventilation can be frequently found in existing facilities. It cannot be used any longer due to current regulations. In the living quarter located on the ground floor of the building a 210×150 cm window and a 210×70 cm heater below it with the required temperature of +90°C were designed. The aforementioned required temperature of the heater was selected so that in each case the indoor air temperature is maintained at +20°C, considered to be the minimum thermal comfort level. However, despite the high temperature of the heater, the temperature inside the room is only +19°C in this case. The designed window is tightly closed (no infiltration through window frames). The air is discharged from the ventilated living quarter to the outside through a 12.0 m exhaust duct. The geometry of the examined case is shown in Figure 4.



**Fig. 4.** Axonometric drawing of the model. Case 2.

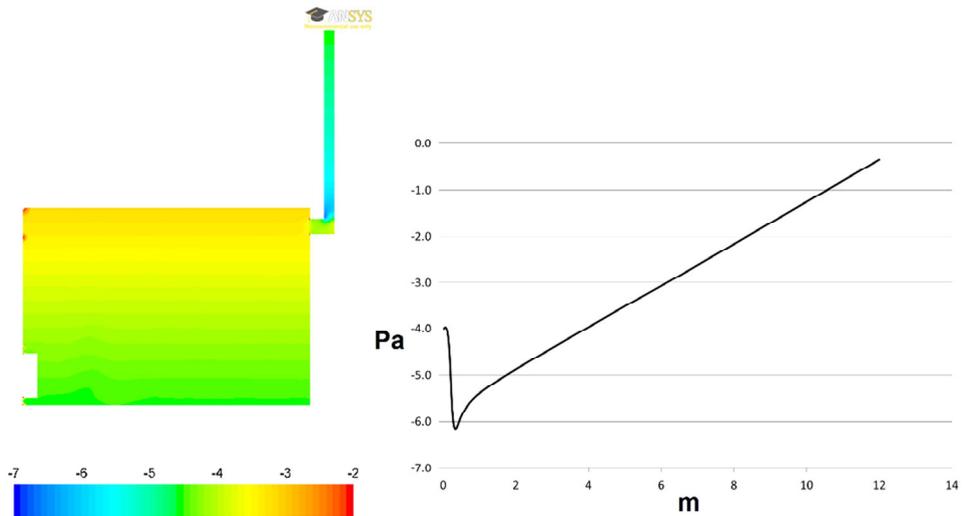
During the computer simulations, the following tests were conducted in Ansys Fluent software:

- Air pressure distribution (the given pressure diagram was measured in Pa) in the living quarter and in the exhaust natural ventilation duct (vertical section of the living quarter and the exhaust ventilation duct) – Figure 5.

Conclusions:

An increase in pressure in the upper part of the room is clearly visible in the longitudinal section. The whole room has a negative pressure compared to the pressure outside. A considerable pressure drop is initially visible in the exhaust chimney, which increases along with the length of the exhaust chimney.

- Vector direction of the airflow (m/s) in the longitudinal section of the room and supply-exhaust ducts as well as in the cross section.

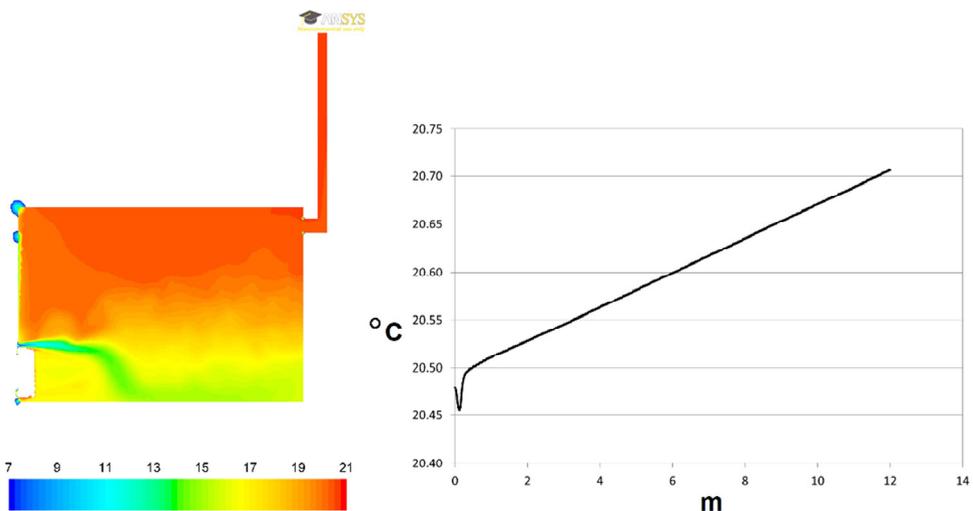


**Fig. 5.** Pressure distribution in the longitudinal section. Diagram showing pressure in the exhaust duct (Pa).

**Conclusions:**

An increased air movement at the level of about 1.8 m/s can be noticed only in the area of air supply and exhaust and near the heater. The air speed inside the room is around 0,3 m/s. The air particles are mixed in the room.

- Distribution of air masses temperature ( $^{\circ}\text{C}$ ) in the longitudinal section and cross section of the living quarter, longitudinal section of the air intake, living quarter and supply and exhaust chimneys, as well as the diagram of air temperature in the chimney ( $^{\circ}\text{C}$ ) – Figure 6.



**Fig. 6.** Distribution of air temperatures ( $^{\circ}\text{C}$ ). Distribution of ventilation air temperatures ( $^{\circ}\text{C}$ ) in a 12-metre exhaust duct.

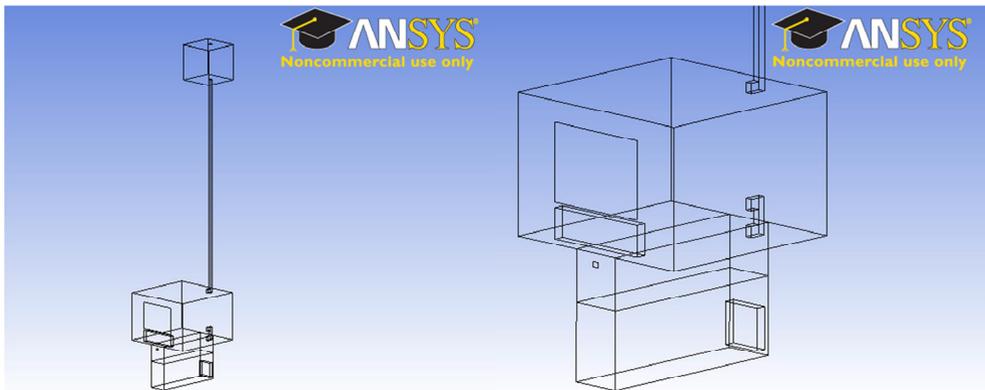
**Conclusions:**

The temperature ranges from  $+15^{\circ}\text{C}$  in the lower part of the room to around  $+21^{\circ}\text{C}$  in the upper part of the room. The average indoor temperature is  $+19^{\circ}\text{C}$ . The air temperature in the exhaust chimney increases slightly as the length of the chimney increases and remains at around  $+20.65^{\circ}\text{C}$ .

The outdoor air (+3°C) is supplied to the room through the window ventilation and heated up to a temperature of approximately +15°C by the heater. According to computer calculations, the ventilation air stream is  $0.0267 \text{ kg/s} = 80.1 \text{ m}^3/\text{h}$ . This accounts for 1.85 times the air exchange in the room.

### 2.3 The third case

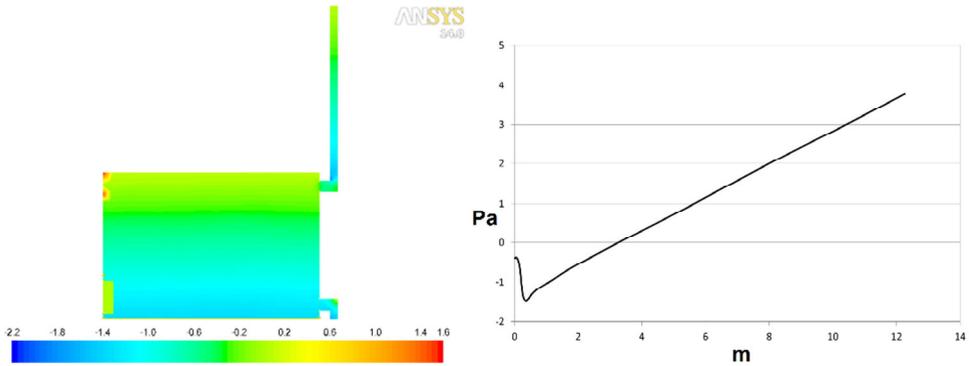
The third case presents a living quarter on the ground floor with an area of  $16.0 \text{ m}^2$  and a volume of  $43.2 \text{ m}^3$ , ventilated with natural balanced ventilation ducts with a cross section of  $14 \times 14 \text{ cm}$  ( $196 \text{ cm}^2$ ), enlarged to  $14 \times 21 \text{ cm}$  in the supply part. The air inflow is provided by a duct led from the air intake located in the basement of the building. The air intake is a room with an area of  $4.0 \text{ m}^2$  and a volume of  $10.0 \text{ m}^3$ . The outdoor air at the temperature of +3°C flows into the intake through a  $14 \times 14 \text{ cm}$  opening. The intake room must have finished walls and the floor as washable surfaces, easy to clean, and it should be equipped with a heater, which heats the incoming outdoor air in this case. The temperature of the heater in the air intake is +70°C. The heated air is supplied from the intake to the living room through a 60 cm long supply duct with a cross section of  $196 \text{ cm}^2$ . In the living room located on the ground floor of the building there is a  $210 \times 150 \text{ cm}$  window and a  $210 \times 70 \text{ cm}$  heater with the required temperature of +35°C below it. The aforementioned required temperature of the heater was selected so that in each case the indoor air temperature is maintained at +20°C, considered to be the minimum thermal comfort level. The designed window is tightly closed (no infiltration through window frames). The air is discharged from the ventilated living room to the outside through a 12.0 m exhaust duct ending with a “solar chimney” measuring  $2.0 \times 2.0 \times 2.0 \text{ m}$  ( $8 \text{ m}^3$ ), with the air at the temperature of +25°C inside. The geometry of the examined case is shown in Figure 7.



**Fig. 7.** Axonometric drawing of the model with a solar chimney. Case 3.

During the computer simulations, the following tests were conducted in Ansys Fluent software:

- air pressure distribution (the given pressure diagram was measured in Pa) in the living quarter and in the exhaust natural ventilation duct (vertical section of the living quarter and the exhaust ventilation duct) – Figure 8.



**Fig. 8.** Pressure distribution in the longitudinal section. Diagram showing pressure in the exhaust duct (Pa).

**Conclusions:**

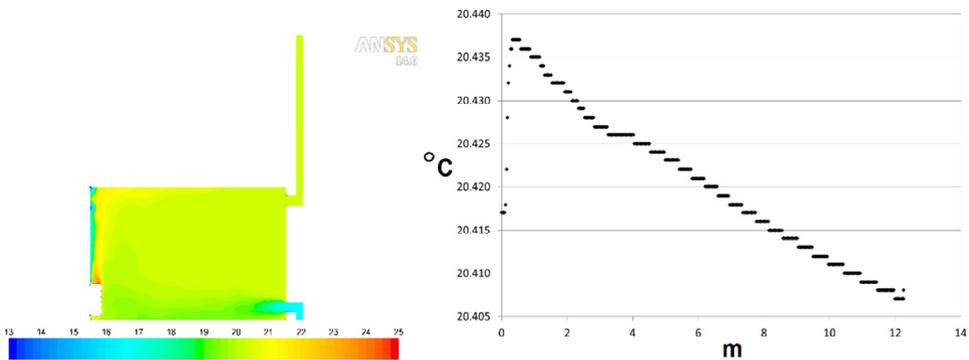
An increase in pressure in the upper part of the room is clearly visible in the longitudinal section. There is positive pressure at the top of the room and a negative pressure at the bottom as compared to the external pressure. The pressure drop is initially visible in the exhaust chimney, which increases along with the length of the exhaust chimney.

- Vector direction of the airflow (m/s) in the longitudinal section of the room and supply and exhaust ducts as well as in the cross section.

**Conclusions:**

It is possible to observe an increased air movement at the level of about 1. m/s only in the area of air supply and exhaust and near the heater. The air speed inside the room is about 0.2 m/s. The air particles get mixed in the room.

- Distribution of air masses temperatures ( $^{\circ}\text{C}$ ) in the longitudinal section and cross section of the living quarter, the longitudinal section of the air intake, living quarter and supply and exhaust chimneys, as well as the diagram of air temperature in the chimney ( $^{\circ}\text{C}$ ) – Figure 9.



**Fig. 9.** Distribution of air temperatures ( $^{\circ}\text{C}$ ). Distribution of ventilation air temperatures ( $^{\circ}\text{C}$ ) in a 12-metre exhaust duct.

**Conclusions:**

The temperature ranges from  $+18^{\circ}\text{C}$  in the lower part of the room to around  $+21^{\circ}\text{C}$  in the upper part of the room. The average indoor temperature is  $+20^{\circ}\text{C}$ . The air temperature in the exhaust chimney decreases slightly as the length of the chimney increases and remains at around  $+20.41^{\circ}\text{C}$ .

In the intake the outdoor air ( $+3^{\circ}\text{C}$ ) is heated to a temperature of about  $+14^{\circ}\text{C}$ , then additionally heated to a temperature of about  $+16^{\circ}\text{C}$ , by means of the heater located in the

lower zone, it is supplied through the supply duct to the living room. In the “solar chimney” the temperature reaches +23°C. According to computer calculations, the ventilation airflow is 0,0237 kg/s = 71,1 m<sup>3</sup>/h., which accounts for about 1.6 times the air exchange in the room.

### 3 Final conclusions

The main reasons for discussing the above topic include:

- improvement in the natural ventilation system performance in new buildings and in existing facilities subjected to thermal renovation (insulation of external walls, installation of new airtight windows and doors),
- outdated standard design guidelines (old norms and regulations) regarding gravity ventilation,
- poor air quality in the rooms and the health hazards associated with it,
- energy savings usually obtained by means of limiting the airflow in the building,
- maintenance of good technical condition of building elements and building equipment (no dampness or mould formation).

In all of the above cases, an increase in pressure in the upper part of the room is clearly visible. In the first and third cases, the temperature inside the room is maintained at around +20°C, resulting in the minimum thermal comfort in the living quarter tested. In the second case with a window ventilator, there occurs a local cooling of the air, which is an undesirable phenomenon due to health reasons. The indoor temperature in this living quarter is only +19°C (minimal thermal comfort is not obtained). The highest air exchange rate was obtained in the second case (80,1 m<sup>3</sup>/h), then in the third case (71,1 m<sup>3</sup>/h), and finally in the first case (67,5 m<sup>3</sup>/h). The proposed solution for a natural balanced ventilation system ensures adequate air exchange.

### References

1. J. Ferencowicz, *Wentylacja i klimatyzacja*, (Warszawa, Arkady. 2<sup>nd</sup> edition, 1964)
2. Polski Związek Inżynierów i Techników Budownictwa: Poradnik inżyniera i technika budowlanego, 2 part III, 373 and 385, (Warszawa, 1968)
3. The Ordinance of the Minister of Infrastructure, *W sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie*, (Dz. U. No. 75, item 690) with amendments. (2015)
4. PN-83/B-03430 (with the A3: 2000 amendment), *Wentylacja w budynkach mieszkalnych, zamieszkania zbiorowego i użyteczności publicznej. Wymagania* (1983)
5. T. Kusionowicz, *Problemy projektowania budynków mieszkalnych, a zdrowie człowieka*, (Kraków. Cracow University of Technology, Architecture Series, **52**, 43, 51, (2008)
6. T. Gaczoł, *JCEEA*, **63** (3), 85–94 (2016)