Natural balanced ventilation. Simulations part 2

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Abstract. The paper is devoted to test results of air flow through natural ventilation supply-exhaust ducts in the rooms located on the upper floor of the building that were conducted in ANSYS Fluent software. 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" that is usually a glass superstructure, located on the roof of the building above the ventilation ducts. 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. The simulations concerned such issues as: pressure system inside the room and in the exhaust duct, distribution of air temperatures in the room, vector direction of air flow through supply and exhaust ducts and in the room. Tests conducted using a computer method of air flow analysis in ducts and in the analysed room indicate that the developed natural balanced ventilation system is a good solution, especially when building sealing is so common. 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 (second part) describes test results concerning the room located on the upper floor of the building, i.e. with a long 9-meter long supply duct and a short 3-meter long exhaust duct.

1 Introduction

Natural ventilation consists in the exchange of air resulting from pressure differences that takes place continuously through ventilation ducts. It is an old, reliable and commonly used way of ventilating rooms. Bad design solutions result in its ineffective functioning. The most common mistake made by designers is the wrong selection of the cross-section of the surface area of the exhaust ventilation duct in relation to its height, and thus to the air draft inside it. The standard requirements regarding the necessity to ensure adequate air exchange rate or air flow rate measured in m^3/s are frequently omitted. As a result of this negligence, there are various effects of room ventilation occurring on different floors. The following article aims to discuss and popularize the method developed by the author that allows one to obtain the same results of properly functioning air exchange system on

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each floor. The solution presented here 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 natural 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 correct negative air ionization. A satisfactory 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 natural ventilation.

2 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 related to improperly functioning natural ventilation that operates periodically and with variable efficiency. The existing residential buildings in Poland are, in the vast majority of cases, created on the basis of a natural ventilation system. The main reasons for discussing the 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 living quarters 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).

3 A natural balanced ventilation system

Natural 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 that in the entire interior the pressure is lower than the atmospheric one. This type of ventilation is called exhaust natural ventilation [1],[2]. The system works smoothly, provided that there is a constant inflow of external air to the ventilated rooms [3],[4]. As a result of fitting new airtight window and door frames, thermal modernization of buildings, 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 resulting in many unpleasant consequences, including life and health hazard [5].

The natural balanced ventilation system is equipped with air intake sets that guarantee a proper inflow of air into the room or two ducts responsible for the inflow and outflow 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^{o}C.

3.1 The first case

The first case presents a room on the upper floor with an area of 16.0 m^2 and a volume of 43.2 m^3, ventilated with natural balanced ventilation ducts with a cross section of 14×14 cm (196 cm^2), enlarged to 14×21 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 m^2 and a volume of 10.0 m^3. The outdoor air at a temperature of +3^{o}C flows into the intake through an 14×14 cm opening. The walls and floor in the intake room must be finished as washable surfaces that are easy to clean and there should be a heater, which heats the incoming outdoor air in this case. The temperature of the heater in the air intake is +90°C. The heated air is supplied from the intake to the living quarter through a 9-metre long air duct with a cross section of 196 cm^2. The living quarter located on the upper floor of the building has a 210×150 cm window and a 210×70 cm heater with the required temperature of +65°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°C, considered to be the minimum thermal comfort level. The window designed in the room is tightly closed (no infiltration through window frames). The air is discharged from the ventilated room to the outside through a 3-metre long exhaust duct. The geometry of the examined case is shown in Figure 1.

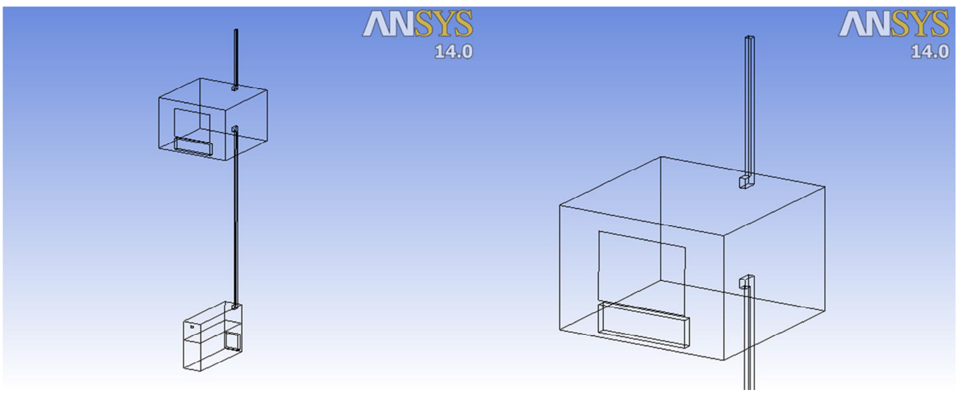


Fig. 1. Axonometric drawing of the model. Case 1.

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

- air pressure distribution (the given pressure graph 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.

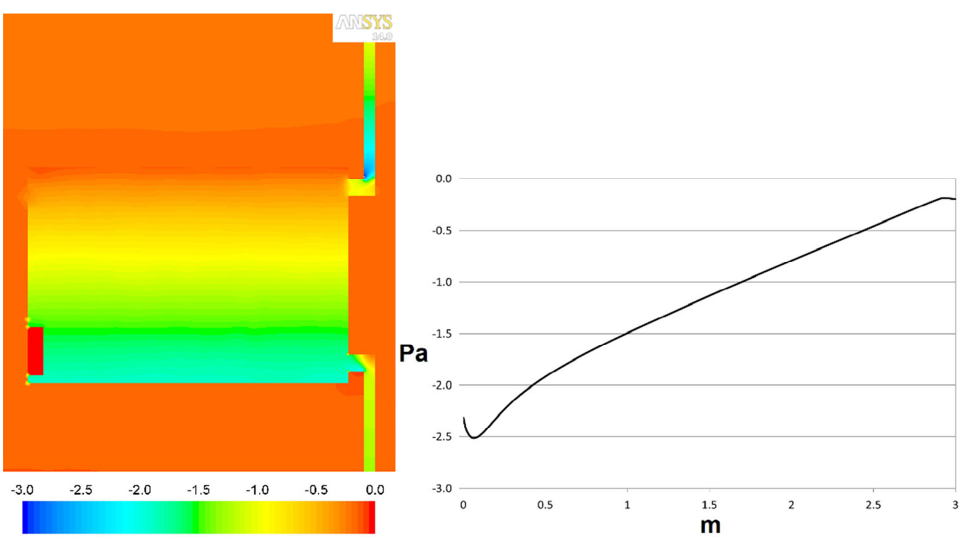


Fig. 2. Pressure distribution in the longitudinal section. Diagram showing pressure in the exhaust duct (Pa).

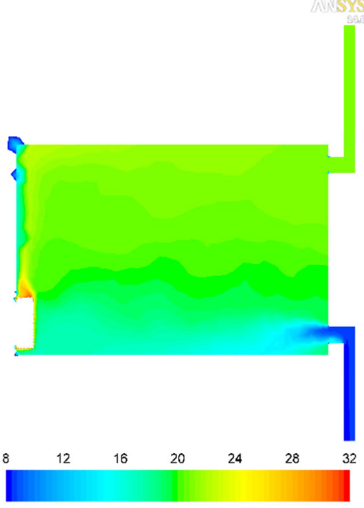
Conclusions:
There is an increase in pressure clearly visible in the longitudinal section in the upper part of the room where there is positive pressure. Initially, there is a noticeable drop in pressure in the exhaust chimney, but it increases along with the length of the exhaust chimney.

- 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:
An increased air movement at the level of about 1 m/s can be observed only in the area of air supply. In the exhaust duct and near the heater, it is around 0.5 m/s. The air speed inside the room is around 0.3 m/s. The air particles get mixed.

- distribution of air masses temperature (°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 graph showing air temperature in the chimney (°C). Figure 3.

Conclusions:
The temperature ranges from +16°C in the lower part of the room to around +22°C in the upper part of the room. The average indoor temperature is +20°C. Initially the air temperature in the exhaust chimney slightly increases, then decreases as the length of the chimney increases and remains at around +21.12°C.



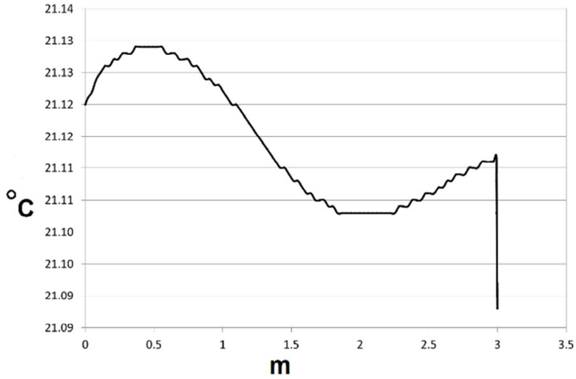


Fig. 3. Distribution of air temperatures (°C). Distribution of ventilation air temperatures (°C) in a 3-metre exhaust duct.

The outdoor air (+3°C) is heated in the air intake up to a temperature of about +5°C, then additionally heated to a temperature of about +12°C by means of a heater placed in the lower zone it is supplied through the supply duct to the living quarter. As the computer calculations indicate, the ventilation air stream is 0.0235 kg/s = 70.5 m^3/h, which accounts for about 1.6 times the air exchange in the room.

3.2 The second case

The second case presents a room on the upper floor with an area of 16.0 m^2 and a volume of 43.2 m^3, ventilated with natural balanced ventilation ducts with a cross section of 14×14 cm (196 cm^2), enlarged to 14×21 cm in the supply part. The air inflow is provided

 https://doi.org/10.1051/e3sconf/20184900026

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 +65°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. 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 3-metre long exhaust duct. The geometry of the examined case is shown in Figure 4.

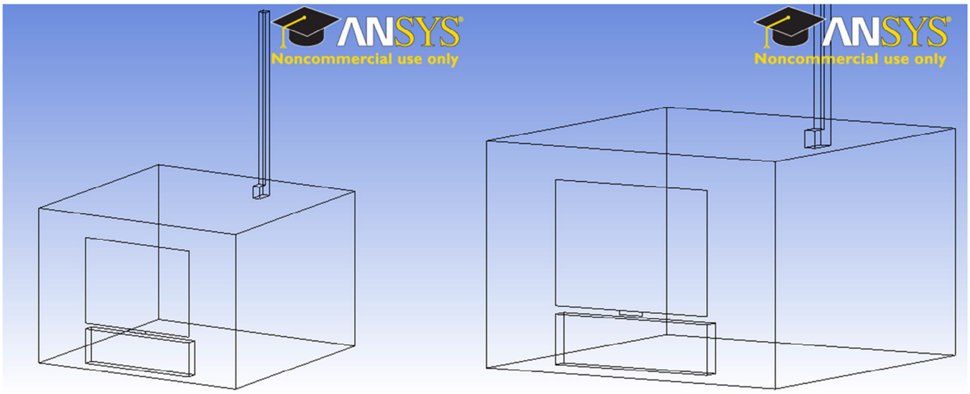


Fig. 4. Axonometric drawing of the model. Case 2.

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

- air pressure distribution (the given pressure graph 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 5.

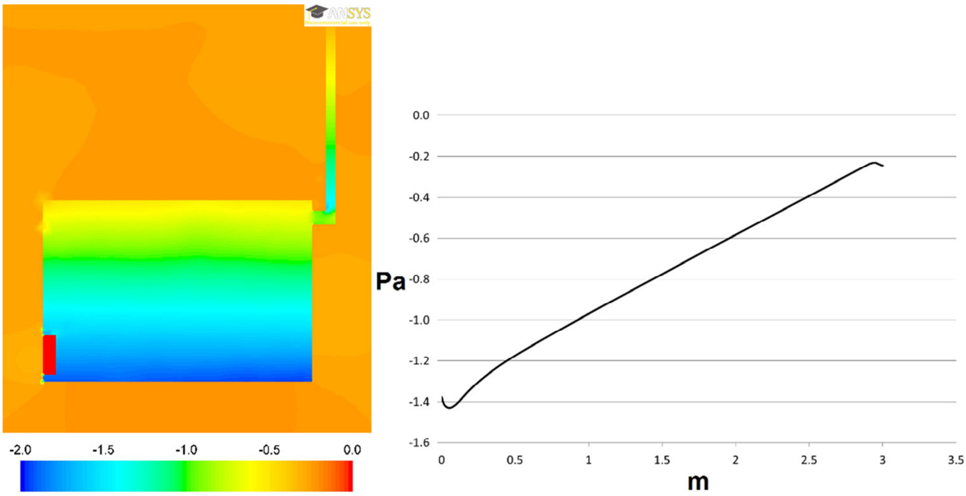


Fig. 5. Pressure distribution in the longitudinal section. Graph showing pressure in the exhaust duct (Pa).

Conclusions:

An increase in pressure in the upper part of the room is clearly visible in the longitudinal section. The whole room has a relatively small negative pressure compared to the pressure outside. Initially, there is a noticeable drop in pressure in the exhaust chimney, but it 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.

Conclusions:

An increased air movement at the level of around 1 m/s can be noticed only in the area of air supply. In the exhaust duct and near the heater, it is around 0.8 m/s. The air speed inside the room is around 0.3 m/s. The air particles get mixed in the room.

- distribution of air masses temperature (^{o}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 graph showing air temperature in the chimney (^{o}C). Figure 6

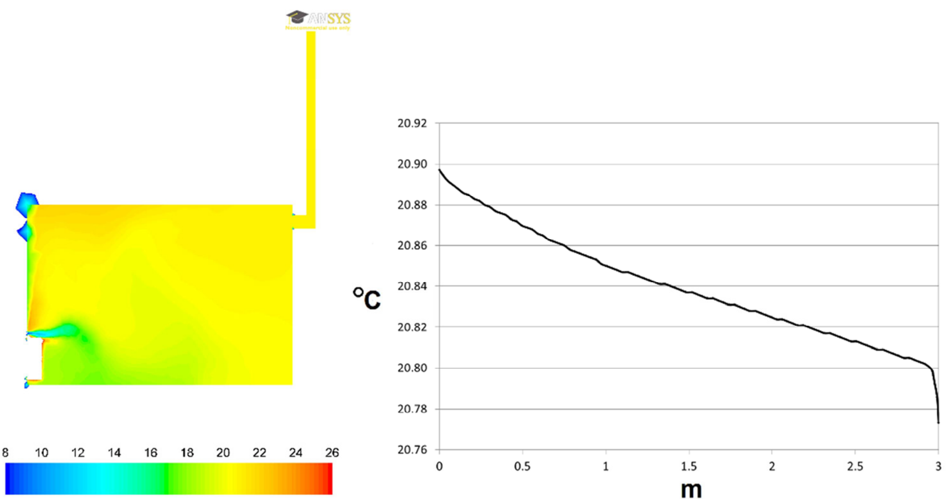


Fig. 6. Distribution of air temperatures (^{o}C). Distribution of ventilation air temperatures (^{o}C) in a 3-metre exhaust duct.

Conclusions:

The temperature ranges from +18^{o}C in the lower part of the room to around +22^{o}C in the upper part of the room. The average indoor temperature is +20^{o}C. The air temperature in the exhaust chimney decreases slightly as the length of the chimney increases and remains at around +20.84^{o}C.

The outdoor air (+3^{o}C) is supplied to the room through the window ventilation and heated up to a temperature of approximately +16^{o}C by the heater. As the computer calculations indicate, the ventilation air stream is 0.0148 kg/s = 44.4 m^3/h, which accounts for 1 time the air exchange in the room.

3.3 The third case

The third case presents a room on the upper floor with an area of 16.0 m^2 and a volume of 43.2 m^3, ventilated with natural balanced ventilation ducts with a cross section of 14×14 cm (196 cm^2), enlarged to 14×21 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

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an area of 4.0 m^2 and a volume of 10.0 m^3. The outdoor air at the temperature of +3°C flows into the intake through a 14×14 cm opening. The walls and the floor in the intake room must be finished as washable surfaces, easy to clean, and the room 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 quarter through a 9-metre long supply duct with a cross section of 196 cm^2. In the living room located on the ground floor of the building there is a 210×150 cm window and a 210×70 cm heater with the required temperature of +40°C below the window. 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 3-metre long exhaust duct ending with a "solar chimney" measuring 2,0 × 2,0 × 2,0 m (8 m^3), with the air at the temperature of +25°C inside. The geometry of the examined case is shown in Figure 7.

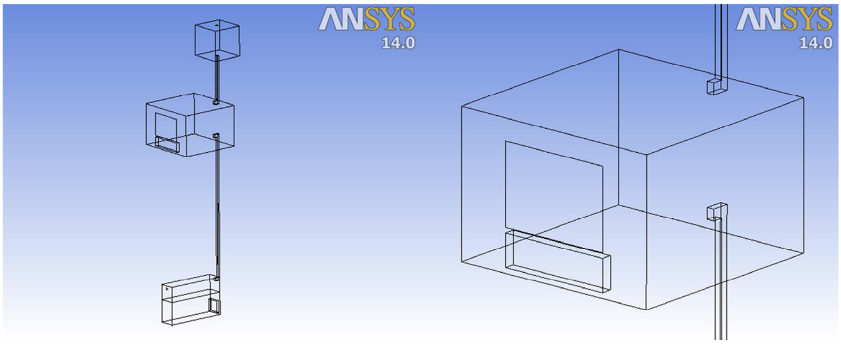

Fig. 7. Axonometric drawing of the model with a solar chimney. Case 3.

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

- air pressure distribution (the given pressure graph 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.

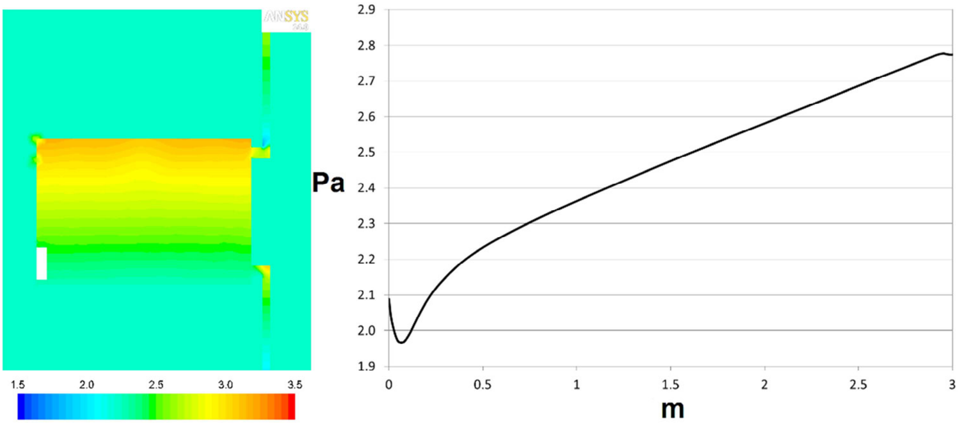

Fig. 8. Pressure distribution in the longitudinal section. Graph showing pressure in the exhaust duct (Pa).

Conclusions:

An increase in pressure in the upper part of the room is clearly visible in the longitudinal section. There is positive pressure as compared to the external pressure in the entire room. Initially, there is a noticeable drop in pressure in the exhaust chimney, but it 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 air exhaust. The air speed inside the room is about 0.3 m/s. The air particles get mixed in the room.

- distribution of air masses temperatures (°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 graph of air temperature in the chimney (°C). Figure 9.

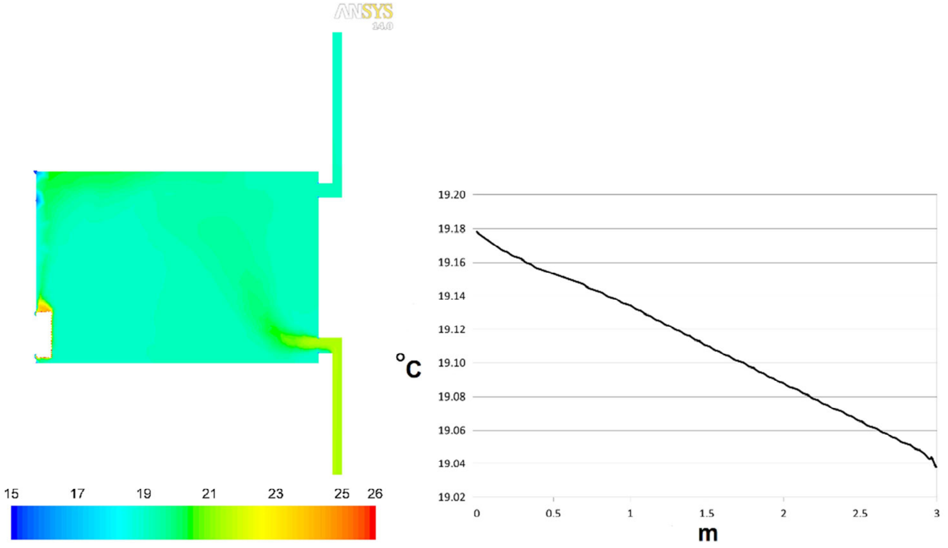

Fig. 9. Distribution of air temperatures (°C). Distribution of ventilation air temperatures (°C) in a 3-metre exhaust duct.

Conclusions:

The temperature ranges from +19°C in the lower part of the room to around +21°C in the upper part of the room. The average indoor temperature is +20°C. The air temperature in the exhaust chimney decreases slightly as the chimney length increases up to the level of +19.04°C.

In the intake the outdoor air (+3°C) is heated to a temperature of about +10°C, then additionally heated to a temperature of about +18°C by the heater located in the lower zone, it is supplied through the supply duct to the living quarter. In the "solar chimney" the temperature reaches +23°C. As the computer calculations indicate, the ventilation airflow is 0.0233 kg/s = 69.9 m^3/h, which accounts for about 1.6 times the air exchange in the room.

4 Final conclusions

In all of the above cases, an increase in pressure in the upper part of the room is clearly visible. Also the temperature inside the room is maintained at around +20°C in all cases, 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 reason. The highest air exchange rate was obtained in the first case (70.5 m^3/h), then in the third case (69.9 m^3/h), and finally in the second case (44.4 m^3/h), probably due to the short exhaust duct and the lack of adequate draft in the chimney. The solution proposed for a natural balanced ventilation system ensures adequate air exchange.

References

1. Ferencowicz J., (*Wentylacja i klimatyzacja*". Warszawa, Arkady. 2nd edition, 641, 1964)
2. Polski Związek Inżynierów i Techników Budownictwa: (*Poradnik inżyniera i technika budowlanego*". Warszawa, Arkady, vol. 2 part III, pp. 373 and 385,1968)
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*"
5. Kusionowicz T.: „Problemy projektowania budynków mieszkalnych, a zdrowie człowieka". Monograph, Kraków. Cracow University of Technology, Architecture Series, 43, 51, 52 (2008)
6. Gaczoł T., JCEEA **63** (3), 85–94 (2016)