"Environmental Engineering" 10th International Conference
Vilnius Gediminas Technical University
Lithuania, 27–28 April 2017
http://enviro.vgtu.lt

eISSN 2029-7092 / eISBN 978-609-476-044-0

Article ID: enviro.2017.269
DOI: https://doi.org/10.3846/enviro.2017.269

Enhancement of Gravity Ventilation in Buildings

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Abstract. Nowadays, people are looking for solutions related to ventilation, cooling or heat demand systems, which would be energy efficient and, at the same time, would not cause the degradation of the surrounding environment. As far as ventilation is concerned, an good solution is a natural ventilation, which improves thermal comfort rooms without increasing the consumption of electrical energy in the building. In order to improve the mode of action of the natural ventilation in the building, one can mount various elements supporting the air flow. One of them is a solar chimney. In order to check the correct operation of a gravity ventilation installation in Poland's climatic conditions, the measurements was carried out on a test stand on the 3.1 building of UTP University of Science and Technology in Bydgoszcz. The received results show the intensification of the air flow through the room the value between 50% and 150%, depending on a measuring hour (Chen *et al.* 2003). These research results were compared with the research results received before the installation of the solar chimney on the ducts of the gravity ventilation.

Keywords: solar chimney, natural ventilation, assisted gravity ventilation.

Conference topic: Energy for Buildings.

Introduction

In the construction industry most energy is used for heating, air conditioning and ventilation of rooms. It has long been aspired to reduce the consumption of electrical energy obtained in a traditional way that is harmful to the environment. Therefore, renewable energy sources meet new expectations in this field, as they are already widely used to reduce the energy consumption of the buildings. People spend most of their time in the office or at home. The quality of the air we breathe has a great impact on our physical and mental state. If the gravity ventilation, which most of the houses and flats are equipped with, does not function properly and does not remove the vitiated air outside, the fresh air does not get inside and the microclimate of the interior is improper. To prevent this, many designers recommend that buildings should be equipped with mechanical ventilation, which unfortunately consumes a lot of electricity. The truth is that the gravity ventilation for most of the year works satisfactorily. The problem appears in the summer, when the outdoor temperature is high. The parameters of the external climate, which influence the inetnsity of the action of natural ventilation, are among others: the intensity of solar radiation, sunshine, the temperature of internal and external air, wind. Weather conditions vary throughout the year, which cause variability of the efficiency of a ventilation system. The gravity ventilation is efficient if there is a big difference in temperature outside and inside the building. Such a situation occurs in winter. The natural ventilation works properly only when the outdoor temperature is lower than the temperature inside the building. It is connected with the difference in air density, which primarily depends on the temperature. When the air density inside the building is less than outside, then the stack effect is correct. The stack effect may not be effiective enough if the difference in temperatures is too slight. Therefore, it is advisable to use such devices that will intensify the air change in the room in a gravitational way.

Poland lies in a temperate climatic zone. The annual value of the sum of solar radiation energy in Poland fluctuates between 950 and 1250 kWh/m^2, depending on the location that is concerned. These conditions are comparable to the conditions, for example, in Germany, the Czech Republic, Slovakia, northern France, southern England, the northern regions of the United States and Canada. In the south of Europe, in Spain or Italy, nearly 2000 kWh of solar energy reaches one square meter per year. However, in the countries of northern Europe, such as Norway or Sweden, this value varies between 500 kWh/m^2 and 900 kWh/m^2 of solar energy per year. For many years, these countries have successfully applied solutions that assist natural ventilation functioning based on solar energy. This article presents the research revealing whether a solar chimney increases the amount of air flowing through the room as a result of the gravity ventilation activity. The capacity of a solar chimney depends on the air temperature in the flue. The amount of heat transmission from solar radiation has a direct impact on the temperature value, and this is connected with the angle of providing sunrays onto the surface. Therefore, the inclination angle of the solar chimney is an important parameter that allows us to define the intensity of natural ventilation. The research on that subject has been carried out since the nineties. Scientists are trying to determine, by means of different methods, optimal values of angles. However, this issue is quite complex because the process of airflow is influenced not only by insolation but also by other factors, for example wind velocity, air humidity. One of the articles (Ahmad *et al.* 2014) presents models of solar chimneys that were simulated in a computer program analyzing the influence of the height, width, inclination angle and size of air duct on the rate of the air flow. According to the authors, an optimal height of the chimney is 2 m and the width of the duct is 0.4 m. The influence of the width on the air velocity in the outlet duct was also the purpose of the research conducted in the tropics by Tan and Wong (Tan, Wong 2013). These studies also show that the ratio of the height of the chimney to its hydraulic diameter should be at least 15, and that the ratio of the height of the solar chimney to its width should be at least 7 so as the flow in the chimney could be two-dimensional. Other researchers were analyzing the effect of the height of the chimney, the effectiveness of the absorption layer, the permeability of the glass layer and the air gap in different conditions (Lee, Strand 2009). Wei together with the research group determined that the optimal ratio of the width to the height of the solar chimney is 1:12, and that the chimney should be as high as the land development conditions and building restrictions make it possible to construct (Wei *et al.* 2011). If the integrated solar chimneys are properly located relative to the pathway of the sun, that is, they "track" the sun throughout the day, the temperature in the room will be almost constant. It should be pointed out that the chimney facing south will achieve the highest efficiency of ventilation. The research by other scientists from Egypt carried out on the model of a cubic room of 1.5×1.5×1.5 m, equipped with three solar chimneys facing different cardinal points proves that if we use one, two, and three chimneys, the indoor temperature of the air decreases by 6%, 10% and 12%. The air flow velocity is also dependent on the number of chimneys and it increases by 13% if there are two chimneys, and even by 33% if there are three chimneys (Hassanein, Abdel-Fadeel 2012). We should also point out that the presented results of the research were conducted in warm countries.

Elements assisting gravity ventilation

According to the Regulation of the Minister of Transport, Building and Maritime Economy of 5 July 2013, ventilation should guarantee a proper quality of inner environment, including air change value, its cleanness, temperature, relative humidity, air movement velocity in the room. These recommendations should be fulfilled subject to all the provisions of legal regulations in force concerning the installation that is mentioned. A ventilation system can be designed as mechanical or gravitational in rooms that are for human beings, in the rooms where windows are not opened, and also in other rooms where air change is essential for health, technology and safety reasons. Taking into consideration the amount of energy that is consumed in mechanical ventilation systems, it is worth mentioning that there are some alternative solutions that enable us to fulfill the provisions and guarantee comfortable conditions in rooms. The first issue connected with a ventilation system is the amount of ventilation air which ought to be supplied to the rooms according to PN-83/B-03430/Az3:2000.

The development of the construction industry caused building sealing which has worsened the air flow in rooms and simultaneously, the needs of users also have changed. It resulted in the increase of demands and the quest for correct solutions to gravity ventilation system. Among numerous ways of supporting the gravity ventilation, the following ones can be listed:

- chimney cowls, whose main task is to increase negative pressure in the return air duct by making use of wind velocity; at a very little wind velocity, shields and ventilators cause additional resistance to the air that is flowing; the increase of wind velocity contributes to the increase of a total pressure value; it is influenced by the difference in air density, and negative pressure that appears in a ventilation casing, which results in a greater intensity of ventilation in the building.
- double glazed walls (double-skin walls), if influenced by solar radiation, create the elevation of air temperature in the interlayer space; in addition, the top envelope functions as a protection against wind and an acoustic baffle; air void that is between the glass layers, functions as a circulation duct. The air, which is heated in the interlayer space, circulates upwards and is removed outside the building. The air draught, which goes up, removes used, warm air, sucking in the cool air at the bottom from the outside. Double glazed walls can also be a barrier against excessive overheating of the building and too big heat gain from the outside. In their article, Brunoro and Rinaldi (2011) describe the effect of double glass on the microclimate of the inside of the building, and they also demonstrate a positive impact on the energy efficiency of this solution.
- glazed atriums and covered passages can be found in the inner area of the building. The air heated at the top part of the atrium is removed outside through the circulation vents, which are installed on the roof part. Then, negative pressure is created and causes, co called "chimney effect" and, as a result, the air is sucked from the bottom parts of the building. The air flowing upward makes fresh air from the bottom part to flow into the building. It is sucked in through the windows that can be opened and are found on the façade. A glazed atrium is a cross-displacement ventilation system. The air, entering through the windows, flows across the rooms. Next, after being heated, the air goes upwards in the atrial space in order to be removed from the building.
- solar chimneys – the device that supports gravity ventilation in the building could be a solar chimney, in which the effect of air convection, heated by solar energy, is used.

The principle of functioning of solar chimneys is similar to traditional chimneys functioning. The characteristic feature is the strengthening of natural displacement ventilation regarding the use of passive heating by solar energy. Gaining the energy from solar radiation is a natural process that takes place thanks to the phenomena of heat and mass exchange.

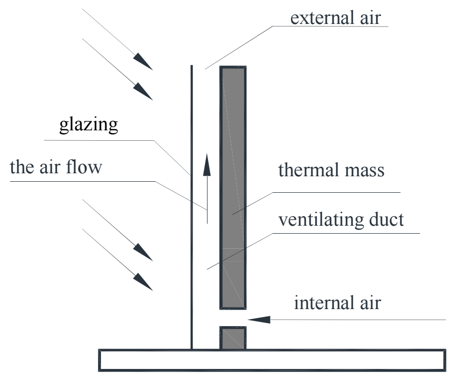

Fig. 1. Schematic diagram of solar chimney

The components of a solar chimney are presented in the figure no. 1 (Nakielska 2015). During a day, the sun warms the test stand through the glazing. The additional heat flux supplied to the air, which is exhausted from the room, causes a temperature rise in the duct and, simultaneously, forces warmer air to flow upwards through the outlet. The rise of the difference of air density that is being exhausted between the inlet and outlet results in the enhancement of the "chimney effect". In addition, the energy stored during a day in the walls is released at night. The energy accumulated at night enables increased velocity of the air flow to be maintained in the duct of a solar chimney. It also causes the intensification of the air exchange at night in the room where the solar chimney is one of the elements of the ventilation system.

Methodology

At the University of Science and Technology in Bydgoszcz, al. Kaliskiego 7, there is a room where the existing gravity ventilation system was modified by adding a new element – a solar chimney. There is old woodwork which made it easy to create real evaluating conditions of functioning gravity ventilation system. The southern side of the chimney is glazed and its inner wall is painted black. The chimney is heated by the sun which leads to the increase in the pressure difference between the inlet and outlet, and increases the flow of warm air. Thanks to that, any impurities and the vitiated air are removed outside. The walls of the chimney store the energy that is released at night. The chimney is 2 meters high above the roof.

Fig. 2. The tested solar chimney

The test stand is a solar chimney made of solid bricks glued together. The material used to build the chimney provides a good storage and giving out of the energy. This superstructure is 0.47 meter long, 1.86 meter wide and 1.45 meter high. Three walls are made of solid brick. The barrier with south exposure is glazing. It is made of Pilkington Optilam 6.4 safety glass 6.33 millimeters thick, with overall solar energy transmittance of 79%, heat-transfer coefficient of 5.7 W/m^2K and a surface area of 2.02 square meters. The walls of solar chimneys insulated outside with ESP 70-0.037 expanded polystyrene 10 centimeters thick and plastered all over.

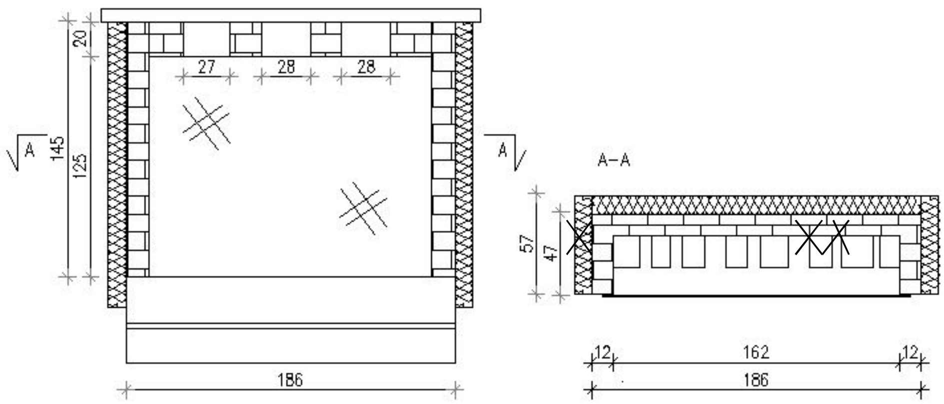

Fig. 3. Technical drawing of the tested solar chimney

The chimney is covered by a reinforced concrete slab and roofing paper. In the room below the superstructure there are 5 vents. The vents are located at a height of 2.5 metres above the floor and their intersecion is 165×165 mm. Each vent is covered by a grate which consists of 30 eyelets that are 0.5 cm wide and 3.5 cm long. The space betweenthe eyelets is 0.5 cm vertically and 0.6 cm horizontally. A total active surface for all the grates is 260 cm^2.

Fig. 4. The vents in the room

The first control measurement was taken on the 9–10 July, 2013 before constructing the test stands. The measurements had been being taken for 24 hours with a parameters reading every 2 hours. The following parameters were measured: the velocity, temperature and humidity of air. The C310 hytherograph was used to take a relative temperature and humidity and the velocity of air was measured by the TA 430 hot-wire anemometer.

The research was done at two testing points: on the roof, directly at the chimney outlet, and in the rooms, on the outlet grilles of the gravity ventilation system. The following parameters were measured:

- air velocity at the level of intake grates, at 9 testing points on each of five grates located in the middle of 9 elementary fields resembling a square in shape, which the grate was divided into (Kołodziejczyk *et al.* 1980),
- air velocity at the level of the solar chimney outlet, measured at 10 testing points located in the middle of 10 elementary fields, which the grate was divided into (Kołodziejczyk *et al.* 1980),
- the temperature and humidity of air inside at specific measuring points that were located in the area where people stayed at 1.2 meter above the floor level.
- the temperature and humidity outdoors.

Results

The first measuring cycle took place on the 20th and 21st July from 2 p.m. to 2 p.m. The outdoor temperature fluctuated between 13.7 and 26.1 °C, the pressure was about 1013 hPa and wind velocity was between 0.1 and 2.4 m/s. Another cycle took place on the 21st and 22nd July from 2 p.m. to 2 p.m. The outdoor temperature was slightly higher, between 14.3 and 27.8 °C, the pressure was about 1011 hPa and wind velocity was between 0.1 and 1.9 m/s.

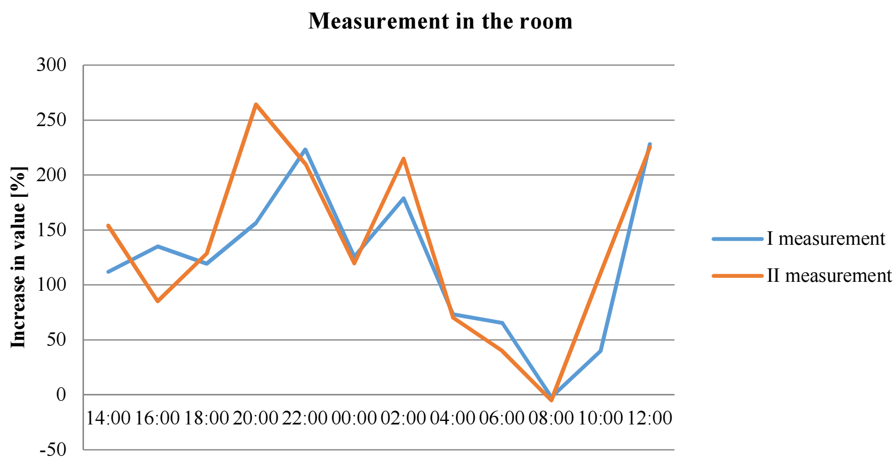

Fig. 5. Measurement in the room

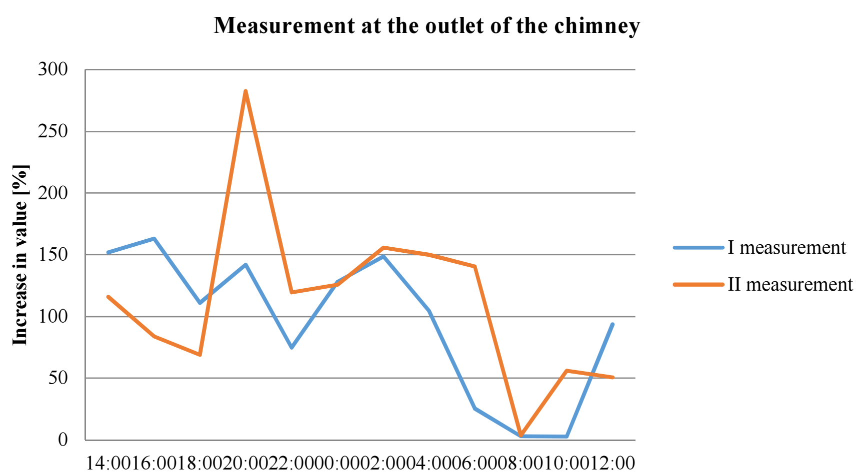

Fig. 6. Measurement at the outlet of the chimney

The value of the air volume flow was measured. Figures 5 and 6 present in a graphical way the percentage change in the air volume flow in the room with the solar chimney in relation to the research carried out before the construction of the solar chimney. Figure 5 presents the research results carried out at the air grates in the rooms. The intensification of the air flow at the grates in the room increases from 4 p.m. until 8 p.m. Then, we can observe a decline in the value with minor fluctuations until 8 a.m. During a day, the intensification of the air change begins to grow. Both study cycles have similar values. The measurements taken at the outlet after the construction of the solar chimney in relation to the measurements without the chimney are presented in Figure 6. The results obtained in the two study cycles are different from each other. The first measurement reaches lower values than the other. The first measuring cycle, which took place on the 20th and 21st July, shows an increase in the air flow between 2 p.m. to 8 p.m. at about 150% in relation to the time when there was no chimney. Then, we can observe some fluctuations, and between 2 a.m. and 8 a.m. there is a drop, that is, the values of the flow are close to those when there was no chimney. Since 8 a.m. the intensification of ventilation has increased. The second measuring cycle taken at 8 p.m. shows an exceptionally high value of the change in relation to the situation before the construction of the chimney. It can be a measuring error or the results could be influenced by external condtions, such as wind. The other values indicate a change of the air flow between 50% and 150%, depending on a measuring hour.

Conclusions

Solar chimneys used in the construction industry are both: an architectural element and a part of a ventilation system, whose main task is to assist the natural ventilation. Thanks to the acquired solar energy, solar chimneys effectively improve the microclimate in a room and unlike mechanical ventilation, they save electrical energy. The results of the measurements of the solar chimney built on the building of the University of Science and Technology in Bydgoszcz indicate the intensification of the air change process both in the measurements taken on intake grates in the room and at the outlet of the chimney. However, we should remember that they cannot be adjusted and it concers both supply and exhaust air.

The presented research constitutes a part of the research conducted on the test stands in Bydgoszcz. Previous results of the measurements can be found in other publications of the authors (Nakielska 2015; Nakielska, Pawłowski 2016; Chalamoński, Nakielska 2015).

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