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# The carbon dioxide generation rate from burning of candle and its effect on room ventilation

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**Abstract.** In construction, the emphasis is currently on high energy efficiency of buildings. A ventilation system ensuring the indoor air quality has a significant share of energy consumption in buildings. Open fire sources, such as gas stoves and candles result in the air pollution in the indoor environment that causes more intensively operation of ventilation systems. The aim of this research is to quantify the pollutants arising from the burning of a randomly selected wax candle that commonly is used in households. Experimental measurements were performed with a special regard to carbon dioxide ($CO_2$) production. The weight loss of the wax during the burning of the candle was has been measured and subsequently the production of $CO_2$ was estimated using a chemical formula. Based on the amount of $CO_2$ produced, the intensity of air exchange using ventilation system has been calculated to achieve the required quality of the indoor environment. The calculated air volume flow rate required to remove the pollutants generated during the burning of the candle is in this case approximately 54% of the air volume flow required per one person.

## 1. Introduction

At present, candles are used as decoration of the house or at celebrations. The products of candles´ burning, such as $CO_2$, belong to the harmful pollutants which need to be removed due to ventilation system. To design a ventilation system correctly, it is necessary to know the amount of air to remove pollutants from indoors. Nowadays, a great emphasis is put on the energy efficiency of buildings and thus there is an effort to minimize air exchange in buildings. When designing buildings, controlled mechanical or hybrid ventilation of buildings is increasingly being considered. To design a ventilation system correctly, it is necessary to know the amount of air to remove pollutants from indoors, which was the subject of research presented in papers [1, 2].

There are several studies around the world investigating the pollutants arising from the process of burning candles. Massoudi and Hamidi [3] have found out that the studied paraffin candles had emitted several dangerous compounds, including hazardous alkenes, and aromatics like toluene and benzene. Derudi et al. [4] characterized the emission factors of different pollutants originating from the candles with special regard to volatile organic compounds (VOCs), which the EU identifies as main indoor pollutants arising from the burning of scented paraffin candles. Another study [5] has reported that products of burning, originating from both cooking and candles burning had represented up to 65% of indoor air pollutants. The study has been performed in 56 housing units over a period of 45 hours. According to study [6], toxic substances such as formaldehyde were produced in large amounts from various scented candles, primarily but not only when they were lit. The linalool and limonene detection rates, representing the most abundant fragrant allergens, was higher than 50% [7]. As it is recommended in [8], it is necessary to ensure sufficient air exchange when burning candles.

Therefore, the objective of this paper is to estimate the sufficient volume flow rate of air needed to ensure the removal of the indoor pollutants originating from candle burning. Because co2 is the major pollutant in candle burning and human respiration, these two sources of pollutants are compared in this study.

## 2. Materials and methods

In order to determine the volume flow rate of air required to ventilate the room in which the candle was burning, it was necessary to quantify the pollutants arising during the burning of the candle. For this purpose, the carbon dioxide as the major burning product was chosen to be monitored. A simple, scented, uncoloured wax candle commonly used in households and restaurants was selected for the investigation. During the experimental measurement, the candle burned in the selected room and the weight loss of the candle, the $CO_2$ concentration and the interior air temperature were continuously measured over a period of 130 minutes. The type of wax has been determined based on the rate of the wax loss and the mass flow of $CO_2$ has been calculated using a chemical formula describing the wax decomposition. From the produced mass flow of carbon dioxide and the permissible concentration in the indoor air, it was possible to calculate the required air flow volume.

### *2.1. Characteristics of the experimental room*

The experimental measurement proceeded in summer season in a five-storey building, in a room situated on the third floor. The floor plan of the room is shown in Figure 1. The dimensions in the figure are given in meters.

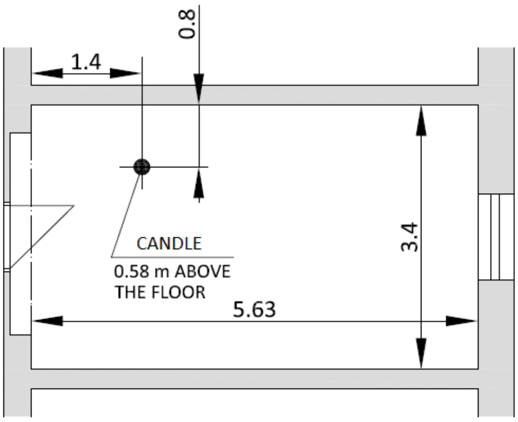


**Figure 1.** Experimental room.

### *2.2. Measuring devices*

A laboratory balance with a separate platform KERN PCD 3000-2 [9], which was used to measure the weight loss of candle wax due to burning, was of these technical parameters: weighing capacity max 3500.00g, readability 0.02g, repeatability 0.02g, linearity 0.05g minimal piece weight 0.2g/piece. The ZG106 [10] instrument with following technical parameters was used to measure $CO_2$ concentration and air temperature around the burning candle: measurement range of $CO_2$: 0 to 3,000ppm, accuracy ± 5%, repeatability ± 20 ppm, temperature range: 0 to 50 °C, display resolution and accuracy ± 1 °C. Since the window was open during the entire measurement time, the measurement of indoor air temperature was for information only.

### *2.3. Characteristics of candle*

A commonly available ordinary non-perfumed candle has been selected for the burning experiment. The original parameters of the candle (diameter, height, weight), measured by a caliper with a measuring range of 0-150 mm with a scale of 0.05 mm, before the experiment were as follows: candle diameter: 21.84 ± 0.01 mm, candle height: 166.62 ± 0.13 mm, candle weight: 55.25 ± 0.003 g, wax color: white. The candle volume has been calculated to be $6.24 \times 10^{-5}$ m$^3$ with a relative error of ± 0.14 m$^3$. The calculated candle density was 885.93 ± 1.28 kg/m$^3$.

## 3. Results and discussion

### *3.1. The measured wax loss*

The mass losses of the candle wax were determined every 5 minutes. Figure 2 presents the trend in mass losses during the 130-minute measuring.

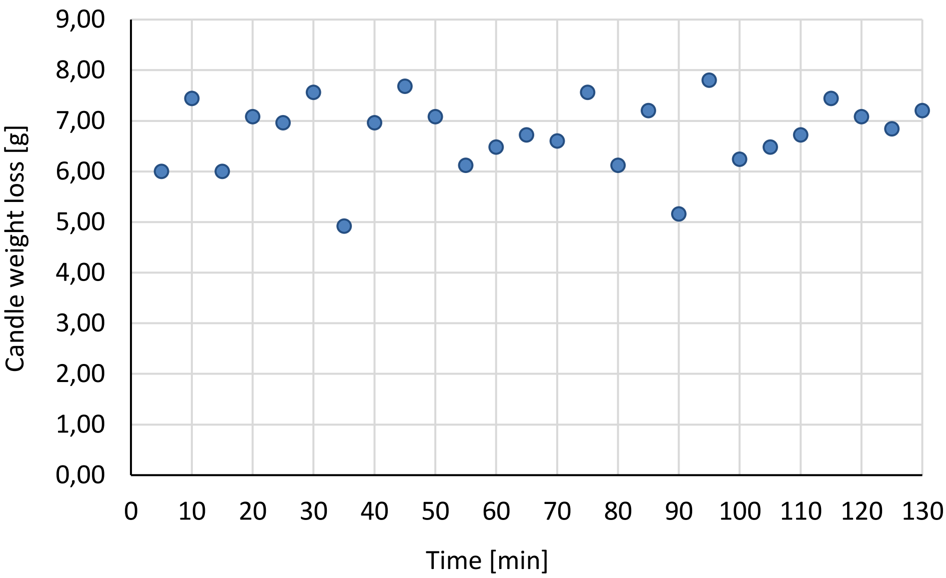


**Figure 2.** The measured losses in wax weight during burning of candle.

As it can be seen in Figure 2, the mass loss rate was uniform during whole experimental period. Based on the 26 data measured, a mean weight loss of wax was calculated of 6.75 g/h with a standard deviation of ± 0.73 g/h and a relative error of 2.12%.

The type of candle wax has been determined according to [11] considering the calculated average wax loss rate. Comparising of the burning rates of the different types of candles reported in the study by Hansen [11], a candle material was identified as palm stearin (vegetable fatty acids from palm oil). Palm stearin wax loss rate reported in Hansen study was 6.78 g/h. The deviation of the wax loss rate for the material from the study [11] and our measured material was 0.44%.

### *3.2. Calculation of the mass flow rate of carbon dioxide*

The measured average air temperature was 28.97 °C with a standard deviation of ± 0.08 °C and a relative error of 0.05%. The measured values of $CO_2$ concentration oscillated around 608.67 ppm with a standard deviation of ± 18.56 ppm and a relative error of 0.59%. This concentration corresponds to the 1095.36 mg/m$^3$, which, when converted to the concentration in the whole model room of volume of 50m$^3$ (Figure 1), gives 54.49 g of $CO_2$ in the room air.

To calculate the theoretical amount of $CO_2$ produced, the chemical equation (1) was used, in which the process of burning a candle made of palm stearin is described [12].

$$2\ C_{57}H_{110}O_6 + 163\ O_2 \rightarrow 114\ CO_2 + 110\ H_2O \tag{1}$$

where $C_{57}H_{110}O_6$ is palm stearin, $O_2$ is gaseous oxygen, $CO_2$ is gaseous carbon dioxide and $H_2O$ is gaseous water. Based on the identified mass loss of the candle (6.75 g/h), the rate of carbon dioxide formation was estimated as 5.28 mg/s. This value corresponds to the theoretical overall produced amount of carbon dioxide originating from burning of 41.2 g per the 130-minute experiment.

The produced $CO_2$ mass flux of a person weighing 80 kg has been calculated according to a study [13] from formula (2).

$$q_m = 0.120406 \cdot m_p \tag{2}$$

where: $q_m$ is $CO_2$ mass flow rate [mg/s] and $m_p$ is body weight of occupants [kg].

The mass flow rate of carbon dioxide produced by a person weighing 80 kg was found as 9.63 mg/s. It can be stated that the $CO_2$ production resulting from candle burning represents approximately 54.83% of the $CO_2$ amount produced by one student when writing a school assignment.

### 3.3. Calculation of the air volume flow rate

Based on the identified $CO_2$ mass flow rate linked to the occupant and the candle, the overall outdoor air volume flow rate can be calculated by applying the formula (3). The estimated air volume is required to ensure a sufficient quality of the indoor air in the room.

$$q_V = \frac{q_m}{C_{IDA} - C_{SUP}} \,.3600 \tag{3}$$

where: $q_v$ is required outdoor air volume flow rate [m$^3$/h]; $q_m$ is $CO_2$ mass flow rate [mg/s]; $C_{IDA}$ is indoor air $CO_2$ concentration [mg/m$^3$] and $C_{SUP}$ is outdoor air $CO_2$ concentration [mg/m$^3$].

As $q_m$ data input for equation (3), we used the $CO_2$ mass flow rates calculated for candle according to chemical equation (1) and for person according to equation (2). The average carbon dioxide concentration of 400 ppm was considered as the background regarding the outdoor air and the $CO_2$ concentration of 1,000 ppm was considered as the maximum in the indoor air.

In this experiment, the required volume flow of ventilation air, that is needed for the reduction of $CO_2$ concentration due to the candle burning was calculated of 17.61 m$^3$/h. Similarly, the required volume flow of air for the reduction of $CO_2$ arising from human respiration was estimated to be 32.13 m$^3$/h (Figure 3).

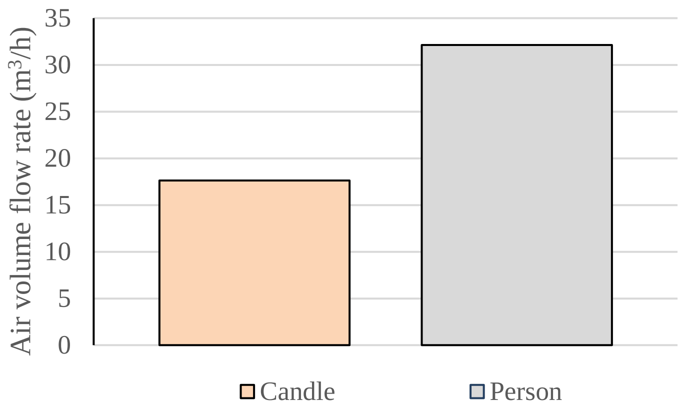


**Figure 3.** The comparison of air volume flow rate required for ventilation due to candle burning and human respiration.

## 4. Conclusion

The experimental findings revealed that burning of the candle has a significant influence on the carbon dioxide pollution in the indoor air. In spite of the fact that the weight of the burning candle represented only 0.07% of the human body weight when considering the average weight of 80 kg, the emissions of carbon dioxide linked to the candle burning represented more than 54% of the $CO_2$ emissions produced by human respiration. It was found that each indoor user of the average weight of 80 kg, performing a sedentary work, produced about 9.63 mg/s $CO_2$ while a burning candle produced 5.28 mg/s.

The needed air volume flow rate is directly proportional to the production of $CO_2$. So, the required air volume flow rate for ventilation of the room connected exclusively to burning of one candle is estimated to 17.61 $m^3$/h, whereas the need for air exchange linked to a person's stay in a room is 32.13 $m^3$/h. It can be stated that when one person is sitting in a room while a candle is burning, approximately 35% of the total ventilation air is required to remove carbon dioxide originating from the candle burning.

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