RENOVATION OF A BUILDING AND ITS IMPACT ON AIR POLLUTION

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ABSTRACT. – Renovation of a building and its impact on air pollution. The main purpose of the research presented in this paper is to quantify the amount of carbon dioxide produced by a standard house with four occupants before and after rehabilitation measures. As expected, these retrofitting actions had a positive effect on energy consumption and, in consequence, the CO_2 emissions decreased significantly. After applying thermal insulation, CO_2 production values derived from heating of the building were reduced by 68 %. The replacement of electrical household appliances decreased CO_2 emissions by 53 %. Also, based on experimental measurements we calculated CO_2 production due to human breathing, for different types of activity. Subsequently, the yearly quantity of CO_2 produced by breathing by a standard four-member family was calculated. Finally, we estimated the contribution of human breathing to the total household CO_2 production.

Keywords: building renovation, indoor air quality, carbon dioxide.

1. INTRODUCTION

Carbon dioxide (CO_2) concentration in the environment is constantly changing, mainly because of human activity impact and is different in specific regions of the world. Every year, scientists find increasingly levels of CO_2 concentration in the atmosphere as a result of human activities and natural processes. According to the measurements done by the atmospheric observatory at the National Oceanic and Atmospheric Administration (NOAA) at Mauna Loa, Hawaii, CO_2 concentrations are now situated above 400 ppm (NOAA, 2017). In comparison, from early scientific research (Etheridge, 1998) conducted in Antarctica and Greenland, climatic data showed that around the year 1,000, the CO_2 concentration was only about 280 ppm. The reason why the CO_2 concentration in the atmosphere had begun to rise sharply is the Industrial Revolution. As the reported value for December 2016 is 404.48 ppm (NOAA, 2017), we can conclude that the concentration of CO_2 in the atmosphere has increased by 44.45 %.

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The most important producers of pollutants are the industry, the transport systems and the buildings. So, human activities affect the natural processes all over the world and, as a result, we have a constant increase of CO_2 concentration in Earth's atmosphere.

The emissions produced by traffic are clearly reducing air quality in densely populated areas. The transport depends on the local flow of people and cars. In the automotive industry there is a great effort to build engines with the lowest production of harmful emissions. According to a research (Theurer 1999), it is possible to reduce emissions by optimizing the layout of the city buildings and by creating a suitable system of roads. These structural modifications have to reduce the concentration of pollutants almost in the same order of magnitude as the measures concerning the number of vehicles and vehicle fleet composition.

In villages and towns, if we leave aside the industry and transport impact, the largest amount of CO_2 is released especially during the cold season, due to energy consumption for heating the buildings.

The buildings have direct consequences on the environment, beginning with the use of raw materials for their structure and ending with their operating mode, where the consumption of natural resources (water and fossil fuels) is leading to harmful emissions. For example, the Polish buildings have the highest average energy consumption for heating (63 % of their buildings are above the European average), while French and Polish buildings have the highest production of air emissions (Balart, 2005).

Serious efforts were made to construct buildings using efficient insulating materials, with thermal conductivity values less than 0.04 W/mK. The evaluation of these materials, in terms of life cycle building energy use, is the subject of several studies (Papadopoulos, 2007).

As previously mentioned, both the building shape and their arrangement in the urban environment can impact on air pollution around buildings (Xie, 2005). These specific measures can contribute to the improvement of air quality in a certain location, but they do not affect the overall worsening conditions of the Earth’s atmosphere.

The CO_2 concentration in different cities may vary. For example, in the city of Kosice in Slovakia, measured CO_2 concentrations are fluctuating between 380 ppm and 550 ppm.

Inside a building, in terms of indoor air quality, major polluters are people, because they produce more pollutants than any other source. A person may perform more or less intense physical activity, but still produces pollutants by breathing and sweating, which are natural metabolic processes. Although the percentage of CO_2 in the air is approximately 0.03 %, for air quality assessment, CO_2 is considered to be the most important component, due to its harmful effects.

This article focuses mainly on the possibility of reducing noxious emissions produced by everyday family life. The aim is to quantify the reduction of energy consumption for a standard household.

2. INCREASING THE ENERGY PERFORMANCE OF BUILDINGS

As a reference building we chose a typical family house, having a standard thermal performance with respect to the majority of buildings that were made during the years of largest construction boom after Second World War in Slovakia. We assume that we have four inhabitants in this family house.

The assessed building was built in 1958 and has only one floor. The house has one living room, one kids room, one bedroom, one kitchen, one toilet and one bathroom. The total floor area of the house is 98.66 m^2. The walls are made of brick and have two types of thickness: 600 mm and 350 mm. The exposed walls area is 147.62 m^2. The ceiling (140.27 m^2) is made of wood, having on top a dry clay layer. The tiled roof is not insulated. The floor (140.27 m^2) consists of wooden boards, laid on sand and slag, directly on the ground. Each individual room has double glazed wooden windows. The door of the house is also made of wood. The total exposed area of windows and door is 18.11 m^2. Calculated energy requirement for heating was 33.707 kWh/year.

Then, the house went through a rehabilitation process. The building envelope was insulated with mineral wool thermal insulation (150 mm in thickness). The old windows were replaced with triple glazed wood-aluminium new windows. The ceiling was insulated with 150 mm XPS hardened polystyrene. The floor was insulated with 80 mm XPS hardened polystyrene. Now, the calculated heat energy demand is only 12,705 kWh/year.

Another option to reduce emissions in a family house (heavily promoted in society) is the replacement of old electrical equipment. In Table 1 (Carbon Footprint, 2016) we documented the annual electricity consumption for older and newer electrical appliances used in our standard home.

Table 1. Electricity consumption of appliances used in the home (Carbon Footprint, 2016)

	The annual energy consumption for older domestic appliances (kWh/year)	The annual energy consumption for new domestic appliances (kWh/year)
Electronics	918	276
Cooking	578	347
Lighting	544	136
Refrigeration	340	170
Washing machine	272	190
Hygiene	238	170
Air conditioning	170	170
Ironing	170	170
Other	170	170

The replacement of electrical equipment in our household generated an important reduction of energy comsumption, from 3,400 kWh/year to 1,731 kWh/year. For a better visual comparison of the effects of the measures in place, we calculated the carbon footprint (Carbon Footprint, 2016).

Before construction renewal, 7.3 t/year of CO_2 were produced from heating the building and 1.7 t/year from electric energy consumed by (old) household appliances. In comparison, family CO_2 production from transport by car is 2.1 t/year, and from transport by train and bus is 0.95 t/year.

After construction retrofitting and after replacing household appliances, only 2.5 t/year of CO_2 were produced from heating the building and 0.8 t/year from energy consumed by (new) household appliances. CO_2 production values calculated for transport remained unchanged.

An unavoidable source of indoor CO_2 pollution is human breathing. In order to obtain the CO_2 mass flow produced by breathing, experimental measurements have been carried out in our house with four-member family. We measured the CO_2 concentration, the indoor air temperature and relative humidity. From the measured values of CO_2 concentration, we calculated CO_2 mass flow rate, produced for different activities: sleeping, sedentary work, light physical work - using the method presented by Kapalo, (2014). CO_2 mass flow rate produced from one person's breathing is: for sleep 7 mg/s, for sedentary activity 11 mg/s, for light physical work 32 mg/s. The total production of CO_2 from breathing for a four-member family is estimated at 1.78 t/year.

3. RESULTS

One of the goals of this research is the evaluation of CO_2 released into atmosphere from our standard house with four residents. Table 2 presents the calculation results from which we can observe different CO_2 production ratios, before and after the actions taken in order to reduce the CO_2 production.

Table 2. Comparing the production of CO_2 before and after measures

	Energy consumption before rehabilitation measures (kWh/year)	**Production of CO_2 before rehabilitation measures (T/year)**	**Energy consumption after rehabilitation measures (kWh/year)**	**Production of CO_2 after rehabilitation measures (T/year)**	**Reducing the production of CO_2 (T/year)**
Heat loss in the building	*31,592*	*6.3*	*10,265*	*2.0*	*4.3*
Heating of ventilation air	*5,115*	*1.0*	*2,440*	*0.5*	*0.5*
Heating total	36,707	7.3	12,705	2.5	4.8
Electrical appliances	3,400	1.7	1,731	0.8	0.9
Breathing (family)	-	1.8	-	1.8	0.0
Transport in town	-	2.2	-	1.1	1.1
Total production	40,107	13.0	14,436	6.2	6.8

From the results shown in Table 2, it can be seen that the largest contribution to CO_2 production (four-member family living in a standard house) is made by heating. After applying thermal insulation, CO_2 production values for compensating heat losses in the building were reduced by 68 %. Sealing the building (new thermal insulation and windows replacement) significantly reduces outdoor air infiltration rate and therefore will generate a 50 % reduction in CO_2 production corresponding to the heating of the ventilation air. The replacement of electrical household appliances reduces CO_2 emissions by 53 %. People's breathing remains unchanged. Targeted arrangement of streets in the city and economical use of vehicles is expected to cut CO_2 emissions by 50 %. Globally, taking into account all the CO_2 emitters, after rehabilitation measures, the CO_2 production rate decreases by 52 %. In Figure 1 we can observe the total CO_2 production before and after the taken measures.

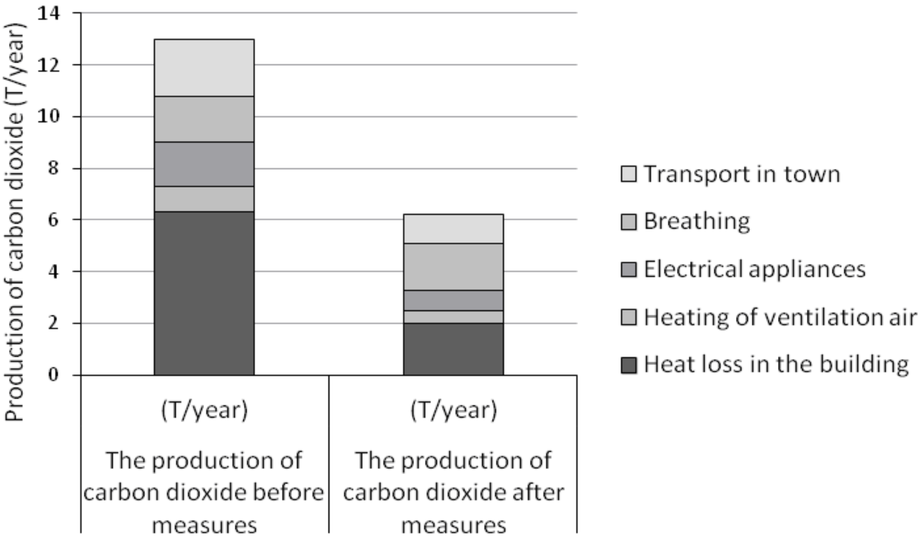

Fig. 1. Comparing the production of CO_2 before and after measures

Before any measures, the four-member family CO_2 breathing contribution was about 14 % of the total production of CO_2. After the implementation of all the measures, the proportion of CO_2 production caused by breathing (which is unchanged in absolute figures) is now 29 %.

4. CONCLUSIONS

This paper examines the effect of house rehabilitation actions in order to reduce energy consumption and subsequently, to decrease CO_2 production.

Also, from experimental measurements carried out in a four-member household we calculated human CO_2 production for the following activities: sleep

7 mg/s, sedentary activity 11 mg/s, light physical work 32 mg/s - all for one person. Subsequently, we calculated the total quantity of CO_2 produced by breathing by a four-member family: roughly 1.78 t/year.

Out of the total 13 t/year CO_2 production for a non-insulated house with older electrical appliances, breathing contribution is 14 %. When the house was insulated, windows and doors were replaced and new energy-efficient electrical appliances were adopted, the total output of CO_2 decreased to 6.2 t/year and the contribution of breathing became 29 %.

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