APARTMENT HOUSE THERMAL REHABILITATION IMPACT ON INDOOR CARBON DIOXIDE RELEASES

P. KAPALO[1], C. BACOTIU[2], F. DOMNITA[2], M. ZELENAKOVA[1]

ABSTRACT. – Apartment building thermal rehabilitation impact on indoor carbon dioxide releases. This article continues the research presented at the last year conference by Kapalo et al. (2017) in the article "Renovation of the building and its impact on air pollution". The main purpose of this study is to quantify the amount of carbon dioxide produced inside an apartment building with 90 occupants, before and after the thermal rehabilitation process. As expected, the improving actions on building thermal insulation had a positive effect on energy consumption and, as a consequence, the CO_2 footprint of the building decreased significantly. After changing the old wooden windows with new tight ones and after using a heat recovery air handling unit, the values of CO_2 production were reduced by 48%, as resulting from the conversion of energy savings due to heating of the building. After applying the thermal insulation on building envelope, the equivalent CO_2 releases of the apartment building were reduced to a final value of 40% compared to the CO_2 footprint before the building thermal rehabilitation.

Keywords: building thermal rehabilitation, window, indoor air quality, CO_2 concentration.

1. INTRODUCTION

Carbon dioxide (CO_2) concentration in the environment increases continuously, mainly in industrial cities. According to last updated data (December 5, 2017) recorded by Mauna Loa (Hawaii) atmospheric observatory (U.S. National Oceanic and Atmospheric Administration - NOAA), the CO_2 concentrations increased during the last year with about 1.61 ppm, from 403.53 ppm in November, 2016 to 405.14 ppm in November, 2017 (NOAA, 2017). From the synthesis report "Climate Change 2014" (IPCC, 2014), where the main world environmental changes and their causes are documented, it can be stated that the globally economic growth is one of the most important drivers of increases in CO_2 emissions from fossil fuel combustion. From the same study (IPCC, 2014), about 12% of the world CO_2 releases in 2010 are generated, directly or indirectly, by producing the needed energy for buildings in order to ensure their adequate operation. According to MacMath (2000) this fact requires an awareness from the

[1] Technical University of Kosice, Faculty of Civil Engineering, 042 00 Kosice, Slovakia,
E-mail: peter.kapalo@tuke.sk martina.zelenakova@tuke.sk
[2] Technical University of Cluj-Napoca, Building Services Faculty, 400 604 Cluj-Napoca, Romania,
E-mail: ciprian.bacotiu@insta.utcluj.ro florin.domnita@insta.utcluj.ro

building industry professionals so they should use in the designing process materials that have a minimal impact on global warming.

This article focuses mainly on the possibility of adjusting the quantity of fresh air needed inside an apartment building with the CO_2 releases of the occupants and to theoretical quantification of the energy savings for a standard household from this building.

2. APARTMENT BUILDING CHARACTERISTICS

The chosen building for this study is an apartment building with 30 flats. The apartment house is located in a town in the eastern Slovakia with 18 thousand inhabitants. The total built area is 2,390 m^2 and the average area of an apartment is about 65 m^2. The exposed walls have an area of 877.40 m^2, they are made of brick and have two types of thickness: 440 mm, respectively 300 mm. Before rehabilitation, the whole building had old wooden windows with a cumulated area of 242.22 m^2. The floor layers were linoleum, concrete, thermal insulation, water insulation, and gravel. The upper floor of the building have attic flats. The total area of sloping roof is 422.06 m^2 and it is made of wood with thermal insulation.

Fig. 1. ***The apartment building after rehabilitation***

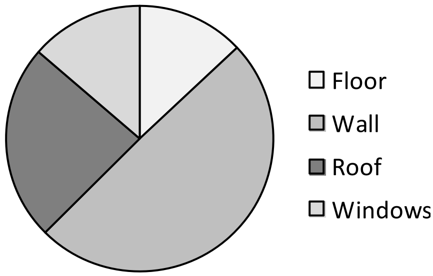

Fig. 2. ***The partition of building elements in envelope area***

In the first phase of the rehabilitation process, the old wooden windows were replaced with new tight, double glazing, plastic windows. A recuperative air handling unit was also installed, in order to provide fresh air inside the building.

In the second phase of rehabilitation, the thermal insulation was added on the exposed exterior walls, roof and floor.

3. CALCULATION OF CO_2 RELEASES

Before the calculation of CO_2 releases, it is needed to determine the energy requirement for heating and for hot water preparation.

The required energy for heating the un-rehabilitated building was calculated according to standard STN 730540 (2016) and the result for the whole apartment building was 160,352 kWh/year. In this case, the recuperative air handling unit did not exist and the ventilation was provided naturally, only through infiltration.

After the first phase of rehabilitation, if the fresh air handling unit is used for ventilation at a rate of $n = 0.5\ h^{-1}$, without heat recovery, the energy needed for heating has a value of 112,147 kWh/year. If the fresh air ventilation rate dropped to $n = 0.15\ h^{-1}$ and the heat recovery was used, the energy requirement for heating has decreased to 58,776 kWh/year.

In the second phase, beside adding the thermal insulation on the exposed walls consisting of 100 mm mineral wool, the roof was insulated with 200 mm XPS hardened polystyrene and the floor with a layer of 80 mm made of the same material. After adding the thermal insulation, it was calculated the energy requirement for heating of 87,747 kWh/year in the case of a fresh air ventilation rate of $n = 0.5\ h^{-1}$, without heat recovery. For a fresh air ventilation rate of $n = 0.15\ h^{-1}$, with heat recovery, the energy requirement for heating dropped at 34,377 kWh/year.

After taking into account the energy requirements for heating the building (heating system and hot water preparation system), the CO_2 releases were calculated according to STN EN 15316 (2010) and Edict 364 (2012). Both systems were the same for each apartment and consist of an individual gas boiler.

The required energy values, calculated for the apartment building in different scenarios, together with the equivalent CO_2 emissions, are documented in Table 1.

Table 1. ***The required energy values and the equivalent CO_2 emissions***

	Energy requirement for heating (kWh/year)	**Equivalent CO_2 production (T/year)**	**Reduction of CO_2 production (T/year)**
Original building state Ventilation without heat recovery	160,352	57.36	-
Building with new windows, Intensity of ventilation $n = 0.5\ h^{-1}$ Ventilation without heat recovery	112,147	44.45	12.91
Building with new windows Intensity of ventilation $n = 0.15\ h^{-1}$ Ventilation with heat recovery	58,776	23.29	34.07
Building with thermal insulation Intensity of ventilation $n = 0.5\ h^{-1}$ Ventilation without heat recovery	87,747	37.78	19.58
Building with thermal insulation Intensity of ventilation $n = 0.15\ h^{-1}$ Ventilation with heat recovery	34,377	13.62	43.74

An unavoidable source of indoor CO_2 pollution is the human breathing. In order to obtain the CO_2 mass flow produced by breathing, experimental measurements were carried out in one of the apartments of the studied building, apartment occupied by a four-member family (Kapalo et al., 2017). There were measured the CO_2 concentration, the indoor air temperature and relative humidity. Based on the measured values of CO_2 concentration, it was calculated the CO_2 mass flow rate, produced during several activities: sleeping, sedentary working, no-intensive physical working - using the method presented by Kapalo et al. (2014).

The CO_2 mass flow rate produced by one person was: 7 mg/s over sleeping, 11 mg/s over sedentary activities and 32 mg/s over no-intensive physical work. Based on these values, the total production of CO_2, released during breathing for the all 90 occupants of the apartment building was estimated at 40.05 t/year.

The replacement of the electrical equipment in the studied household with a new, energy-efficient equipment generated an important decrease of energy consumption, from 102,000 kWh/year to 51,930 kWh/year. For a better comparison between the five different situations studied in this research, the carbon footprint is presented in Table 2.

3. RESULTS

One of the goals of this research was to evaluate how much CO_2 is released into atmosphere from the studied apartment building with 90 residents. In Table 2 we presented the overall results, from which come into view the different CO_2 production ratios, before and after the actions taken in order to reduce the CO_2 production of the whole building.

Table 2. ***The CO_2 production before and after the building rehabilitation***

<table>
<tr><th></th><th>Equivalent CO₂ production for heating the building (T/year)</th><th>CO2 production from electrical equipment (T/year)</th><th>CO2 production from breathing (T/year)</th><th>Total production of CO2 (T/year)</th></tr>
<tr><td>Original building state
Ventilation without heat recovery</td><td>57.36</td><td>51.00</td><td rowspan="5">40.05</td><td>148.41</td></tr>
<tr><td>Building with new windows,
Intensity of ventilation n = 0.5 h-1
Ventilation without heat recovery</td><td>44.45</td><td rowspan="4">24.00</td><td>108.50</td></tr>
<tr><td>Building with new windows
Intensity of ventilation n = 0.15 h-1
Ventilation with heat recovery</td><td>23.29</td><td>87.34</td></tr>
<tr><td>Building with thermal insulation
Intensity of ventilation n = 0.5 h-1
Ventilation without heat recovery</td><td>37.78</td><td>101.83</td></tr>
<tr><td>Building with thermal insulation
Intensity of ventilation n = 0.15 h-1
Ventilation with heat recovery</td><td>13.62</td><td>77.67</td></tr>
</table>

From the results presented in Table 2, it can be seen that the most important contribution to CO_2 production (ninety persons living in the apartment building) was generated by heating the original building or by heating the building with new windows without heat recovery ventilation. After applying the thermal insulation and the heat recovery ventilation, the energy consumption for heating the building has decreased and, as a consequence, the equivalent CO_2 production values dropped significantly. In this case, the largest amount of CO_2 production was released through the occupants' breathing process. Sealing the building (new thermal insulation and windows replacement) significantly reduces outdoor air infiltration rate and therefore generates a decreasing of CO_2 production corresponding to fresh air heating for ventilation. The replacement of electrical household appliances reduces the CO_2 emissions by 53%. The CO_2 production from apartment building occupants remains unchanged in all situations. Overall, taking into account all the five studied scenarios, after rehabilitation measures the CO_2 production rate decreases significantly.

One of the easy and effective ways to conserve the energy is through building insulation (Paraschiv, 2017). An equivalent of 1,5 kg of CO_2 is released during the fabrication process of 1 kg of mineral wool and 3 kg of CO_2 is generated from the polystyrene manufacturing process (MacMath, 2000). In the case of our studied apartment building, a total of 203.57 m^3 of thermal insulation (mineral wool and polystyrene) is needed. Therefore, during its fabrication processes, an equivalent of approximately 8.55 t of CO_2 were produced, much less than the saved quantity of CO_2 due to reduced energy requirements for heating the building.

According to Meggers (2012) material usage in buildings must include consideration for the emissions of the material. The CO_2 emissions from buildings must also be evaluated as a standard part of the design process.

4. CONCLUSIONS

This paper studies the effect of thermal rehabilitation actions carried out to an apartment house in order to reduce the energy consumption and subsequently, to decrease the building CO_2 footprint. Also, based on the experimental measurements performed in a four-member apartment, it was calculated the CO_2 production in the case of several domestic activities performed by one person. Next step was to calculate the total quantity of CO_2 produced by the whole four-member family (around 40.05 t/year). Out of the equivalent total of 148.41 t/year of CO_2 generated by a non-insulated building with older electrical appliances, the occupants contribution is 27%. After the apartment building rehabilitation (thermal insulation was added, windows and doors were replaced, new energy-efficient electrical appliances were adopted and ventilation with heat recovery was in service), the total output of CO_2 decreased by approximately 50%.

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