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CO_2 Balance of Wood Wall Constructions Compared to Other Types of Wall Structures

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***Abstract*—The atmospheric concentration of carbon dioxide is continuously increasing. The residential sector have high rate of emitted carbon dioxide from the different sectors' emission. This study try to show the beneficial effect of renewable materials compared to other silicon based building materials. 80 different house layouts were involved in the comparison, which were carried out with four wall types. The CO_2 equivalences of the external walls were determined to each wall types and each house layouts. The most unfavorable CO_2 balanced structures were the two silicate based materials, brick and concrete wall. These have surplus CO_2 emission. While the light frame structure and the block house store more carbon (in CO_2 equivalence) than these emitted during theirs production. Based on our analysis - beside sustainable sylviculture - the spreading of the wood framed and the block houses would have positive effect on the carbon dioxide concentration located in the air.**

***Index Terms*—CO_2 emission, climate change, house walls.**

I. INTRODUCTION

Recently we hear about climate change at every turn from various information channels. It is often said that since the end of the 18th century, the concentration of carbon dioxide increased dramatically.

According to the latest information the majority of scientists agree that climate change is most likely attributable to human causes [1]. The increase of carbon dioxide concentration is increase primarily resulted from the consumption and burning of fossil energy sources such as oil, gas, and coal [2]-[4]. Previous studies have also shown that the residential sector have high rate (about 30%) of emitted carbon dioxide among the different sectors in the European Union and also in Hungary [5]. The energy consumption is in strong relation with CO_2 emission (see Fig. 1).

There are hundreds of millions of buildings from the quiet large used by group of people to small ones like households, but the small buildings are in vast majority. An individual building complex has a large emission reduction potential, whereas a small percent from a big amount of emission is much more than the whole emission of a household. In other word it is easy to achieve significant emission reductions at the top end of the range of buildings, but it getting harder as the floor space of the construction gets smaller. Even so, the total emission reduction of all the small units could exceed the total emission reduction of large complexes. It is known as long tail effect [7] (Fig. 2).

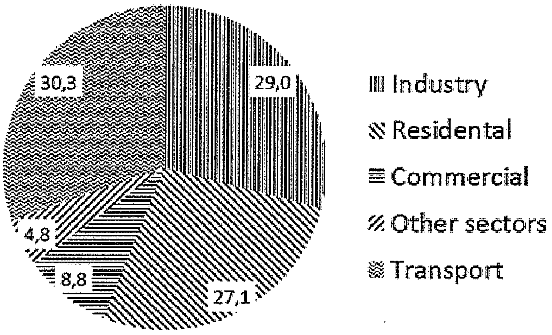

Fig. 1. Energy consumption of sectors [6].

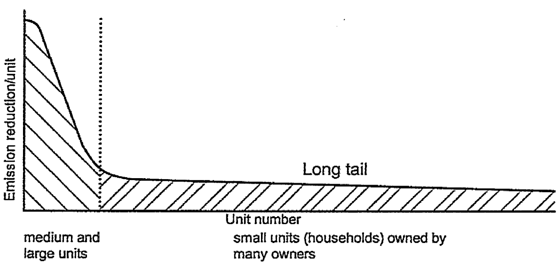

Fig. 2. Long tale distribution of building sector.

Between 1971 and 2004, CO_2 emissions, including the use of electricity in buildings is estimated to have grown at a rate of 1.7% per year in case of households [8].

This raises the question: how can people reduce carbon dioxide emissions? If we examine the floor space and the proportions of the energy consumption of households, we find that the majority of consumed energy – and the associated carbon dioxide emissions – related to the heating and cooling of households and the embodied energy, which built in the building materials. There are several carbon dioxide outputs during the life cycle of the buildings, mainly connected to its operation e.g. keeping comfortable temperature inside the building during whole year. If it would be possible to reduce the energy used for heating, then it could be reduced the associated carbon dioxide emissions, and thereby it helps to reduce the effects of climate change. The second biggest carbon emission area related to residential sector is the up building and demolishing processes of homes. For example carbon dioxide is produced during the manufacturing of building materials. The energy emitted during the production of construction materials is called embodied energy which consequently means carbon dioxide emission. The present article focuses to the embodied energy amount of different wall constructions and do not deal with the demolishing

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process. However, it worth to process further examination and compare the reusability and the possibility of reutilization of silicate based and organic building materials after demolishing, and of course determine the CO_2 cost of it.

Looking at the energy consumption during the life cycle of a house, it can be found that the operating phase use the most energy depending on the physical parameters of the building and numbers of years used for the calculation. Generally the better the heat insulation, the lower the energy consumption is. If operational energy demand can be reduced (e.g. by increase the heat insulations) the importance of the other sections, mainly the manufacturing (embodied energy), can be emphasized [9]. That is why the materials of our buildings matter so much.

The purpose of present study was to compare different houses with different wall types, and estimate the carbon dioxide emissions of them. Other purpose was, to examine the carbon dioxide emission per square meter related to different house constructions and layouts.

II. MATERIALS AND METHODS

80 buildings with different living areas from two wooden housing companies were analyzed. This sample houses were real residential buildings, which built in the past or presently are building. However the buildings were built as a log home construction or wooden frame structure in reality, but they were built virtually by using four different wall structures.

If we want to increase the energy efficiency of buildings with any technology it is unthinkable without the existence of basic thermal requirements. To make the different wall structures comparable, they must have the same thermal property. This can be specified by the heat transmission coefficient named *U*-value. The unit shows how much energy transmit in 1 square meter wall surface if the temperature difference is 1 degree Kelvin between the two sides of the wall. The tightening of European legislation points towards of passive houses in the near future. One of the conditions of passive houses, the net specific energy consumption is max. 15 kWh/m^2/year. This can be achieved with low heat transfer coefficient walls ranged between U=0.10 and 0.15 W/m^2K [10]. Due to the uncertainties in the range, U=0.13 W/m^2K was chosen in this experiment. All wall type was designed to have the same heat transfer coefficient even if they were built in different values. The calculations of layer thickness in the wall have been performed by WinWatt building physics and energetics software. The desired U=0.13 W/m^2K value was insured by altering the thickness of insulation layer in wall structures as long as the whole structure reached the target value.

Four different wall types were selected. Such as: brick, concrete wall insulated on two sides, light wood frame wall and wall made of solid wood [11]. Table I shows the order of the layers of four different walls. Layer 1 is inside layer 5 and 8 is outside.

There are building materials, which can store significant amount of carbon by sequestering this amount during the life cycle. In case of wood this carbon was deprived from the atmospheres decreasing the CO_2 content in the air.

TABLE I: THE STRUCTURE OF THE WALLS FROM INSIDE TO OUTSIDE AND THE CO_2 EQUIVALENCE OF THEM

Layers	Brick wall	Bilaterally insulated concrete wall	Light wood frame wall	Block house with aux inner insulation
1.	15 mm lime cement plaster	15 mm lime cement plaster	12.5 mm gypsum board	20 mm wooden boarding
2.	440 mm brick	50 mm graphitized polystyrene	30 mm air gap, 30 mm lathing	30 mm air gap, 30 mm lathing
3.	10 mm mortar	150 mm cast concrete	Vapor barrier (paper sheet)	12 mm vapor permeable chipboard
4.	50 mm polystyrene	200 mm graphitized polystyrene	80 mm cellulose ins., 80 mm trusses	210 mm blown cellulose insulation, 210 mm spacer
5.	2 mm plaster	5 mm breathable plaster	12 mm vapor permeable chipboard	180 mm glulam spruce
6.			160 mm cellulose insulation 160 mm studs	
7.			50 mm cellulose based insulation board	
8.			5 mm breathable plaster	
kg CO_2/wall m^2	+84.449	+65.546	-25.479*	-67.785*

*minus values shows that the structure can store more carbon than emitted during manufacturing

Oven dried wood comprise around 50 percent carbon what mean 500 kg carbon in every tons of wood. The oxygen content of the carbon dioxide bounded by living trees was released during biological process of the tree. The 500 kg carbon bounded in wood body means around 1850 kg carbon dioxide abstraction from the air. It can be calculated from the molecule weight. In other words 1850 kg CO_2 is necessary to be deprived from the atmospheres for build 1 tons of wood.

There are several studies on the embodied energy of the houses [12]-[15]. In Hungary with the leadership of Medgyasszay an investigation were done about the building materials and constructions [16]. There established emitted CO_2 amounts were used in our estimations. CO_2 equivalence of each wall types (kg CO_2/m^2) was calculated and shown in the last row of Table I. The energy consumed during manufacturing process, so-called Embodied Energy was also expressed in CO_2 equivalence. The materials also contain significant amount of carbon. In this case the Equivalent stored CO_2 was calculated too. And then the final CO_2 equivalence (CO_2 kg/wall m^2) was determined by subtract the equivalent stored CO_2 from embodied energy expressed in CO_2 equivalence According to the building plan the overall outside wall surfaces area were calculated and multiplied with the CO_2 equivalents. In this investigation was not taking into consideration the other parts of the buildings such as roof, foundation or windows and floors.

As the calculations of CO_2 content of overall outside wall of buildings were done, the results could be referred to the floor space.

III. RESULTS

The calculated CO_2 equivalences of each house were plotted as a function of the area of the houses (Fig. 3). As it can be seen in all cases a satisfying polynomial trends could be fitted to the points. The bigger is the area of the house, the more CO_2 is stored or emitted during the manufacturing of the construction depending on the chosen material. The positive CO_2 equivalence means more incremental CO_2 were released in relation with the product, then the bounded CO_2 until installation and vice versa.

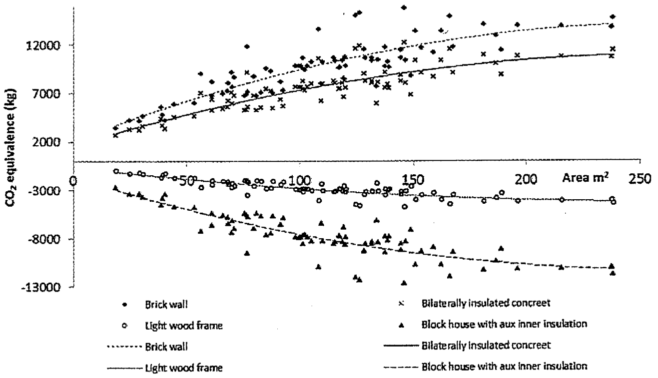

Fig. 3. CO_2 equivalence of different wall types in different house sizes.

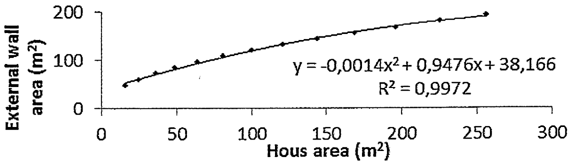

Fig. 4. External wall are in function of house area in case of squared layout.

The equations (1)-(4) belonging to the four wall types are respectively: (1) Brick wall, (2) Bilaterally insulated concrete wall, (3) Light wood frame wall, (4) Block house with aux inner insulation

$$y = -0.1697 \cdot x^2 + 90.463 \cdot x + 2097.3 \quad (1)$$

$$y = -0.1317 \cdot x^2 + 70.214 \cdot x + 1627.8 \quad (2)$$

$$y = 0.0512 \cdot x^2 - 27.294 \cdot x - 632.78 \quad (3)$$

$$y = 0.1362 \cdot x^2 - 72.612 \cdot x - 1683.5 \quad (4)$$

The bigger house area means proportionally smaller external wall area. As the figure show below the trend line become milder with the increasing area. So it means proportionally less building materials belong to the external wall of a bigger house (see Fig. 4).

IV. DISCUSSION

As it was seen, concrete and brick wall manufacturing consumed a great amount of energy, and that's why constructing these types of walls will emit a high amount of carbon dioxide. Silicate based materials having a relative high density especially the concrete what partially explain the high energy consumption during manufacturing. These materials are not able to store significant amount of carbon what could raise the CO_2 equivalence. If the wall were manufacture from renewable wood, the balance will be negative, because of the favorable carbon storage capacity of wood, and the less energy requirement of wood processing [17]-[19]. Of course the log homes contain more wood than frame works. By this the stored carbon amount in log homes makes better the CO_2 equivalence of this type of wall. Although the thermal effectivity of wood frame wall is considerable better because of the space between frame studs is field with insulation material. Consequently the same U value can be achieved in thinner wall thickness in case of frame wall. Wood is favorable after life cycling of wall, because the demolished material can be used in many other ways e.g. chipboard fiber board or energy production by burning.

V. CONCLUSIONS

The increased use of wood-based products has a limited potential to increase carbon storage. However, additional gains may occur if other materials are substituted by wood, those materials which are much higher fossil-energy intensive (e.g. concrete, steel). The energetic utilization of by-products mentioned above makes it possible to substitute further fossil fuel sources.

As it was concluded, the more the wood in the walls of the house, less carbon dioxide is emitted and more carbon is stored. In some cases – especially when a large amount of wood built in – more carbon is stored than emitted during the manufacturing. Traditionally in Hungary the brick buildings are wide spread, consequently the additional carbon storage potential is high. Based on our analysis the spreading of the wood frame and the block houses would have positive effect on the carbon dioxide concentration in the air. Another question is how we can encourage people to build wooden houses. There are regions where the wood and wood frame building amounts the majority of the residential buildings such as in North America or Scandinavia. In these regions the carbon store potential is used actively.

REFERENCES

[1] *IPCC Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014.

[2] P. Bertoldi, B. Hirl, and N. Labanca, *Energy Efficiency Status Report 2012, Electricity Consumption and Efficiency Trends in the EU-27,*

Luxembourg: Publications Office of the European Union, ISBN 978-92-79-25605-9.

[3] A. M. Omer, "Energy use and environmental impacts: A general review," *Journal of Renewable and Sustainable Energy*, vol. 1, no. 5, 2009.

[4] A. Zecca and L. Chiari, "Fossil-fuel constraints on global warming," *Energy Policy*, vol. 38, pp. 1-3, 2010.

[5] IEA Statistics 2011. [Online]. Available: http://www.iea.org/statistics/statisticssearch/report/?&country=HUNGARY&year=2011&product=Balances

[6] (2008). IEA Energy efficiency requirements in building codes, energy efficiency policies for new buildings. [Online]. Available: http://www.iea.org/efficiency/CD-EnergyEfficiencyPolicy2009/2-Buildings/2-Building%20Codes%20for%20COP%202009.pdf

[7] S. Lemmet, *Buildings and Climate Change*, United Nations Environment Programme, ISBN: 987-92-807-3064-7, DTI/1240/PA 2009.

[8] M. Levine, D. Urge-Vorsatz, K. Blok *et al.*, "Residential and commercial buildings," in *Proc. Climate Change 2007: Mitigation, Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, U.K. & New York, NY, U.S.A: Cambridge University Press, Cambridge, 2007.

[9] L. Gustavsson and A. Joelsson, "Life cycle primary energy analysis of residental buidings," *Energy and Buildings*, vol. 42, pp. 210-220, 2010.

[10] Z. Debreczy, "Fundamentals of planning passive house (Passzívházak tervezésének alapjai, in Hungarian)," *Passive House Academy Co.* Budapest, 2011.

[11] Z. Móricz, "Comparing wall construction of buildings by CO_2 balance," *Study*, 2014.

[12] I. Z. Bribián, A. V. Capilla, and A. A. Usón, "Life-cycle assessment of building materials: Compearative analysis of energy and environmental impacts of the eco-efficiency improvement potential," *Building and Environment* vol. 46, pp. 1133-1140, 2001.

[13] A. Shukla, G. N. Tiwari, and M. S. Sodha, "Embodied energy analysis of adobe house," *Renewable Energy*, vol. 34, pp. 755-761, 2009.

[14] G. P. Hammond and C. I. Jones, "Embodied energy and carbon in construction materials," in *Proc. the Institution of Civil Engineers, Energy*, vol. 161, no. 2, pp. 87-98, 2008.

[15] B. V. V. Reddy and K. S. Jagadish, "Embodied energy of common and alternative building materials and technologies," *Energy and Buildings*, vol. 35, pp. 129-137, 2003.

[16] G. Tiderenczl, P. Medgyasszay, Z. Szalay, and Z. Zorkóczy. (2007). [Online]. Available: http://www.foek.hu/korkep/0-0-7-1-.html

[17] T. Karjalainen, S. Kellomäki, and A. Pussinen, "Role of wood-based products in absorbing atmospheric carbon," *Silva Fennica*, vol. 28, no. 2, pp. 67-80, 1994.

[18] K. Pingoud, A. L. Perälä, and A. Pussinen, "Carbon dynamics in wood products," *Mitigation and Adaptation Strategies for Global Change*, vol. 6, pp. 91-111, 2001.

[19] B. Upton, R. Miner, M. Spinney, and L. S. Heath, "The greenhouse gas and energy impacts of using wood instead of alternatives in residential construction in the United States," *Biomass and Bioenergy*, vol. 32, pp. 1-10, 2008.

Zoltán Pásztory was born in Budapest in 1971 and got the BSc in studied wood technology and the MSc in wood engineering at the University of Forestry & Wood Science in 1996, and the MSc in economy at the University of Sopron in 1998 located in Sopron Hungary. He wrote the doctoral thesis at the PhD School of Faculty of Wood Science and Technology, with the topic of "Developing opportunity of heat insulation for light construction buildings" at the doctoral School of University of West Hungary in Sopron.

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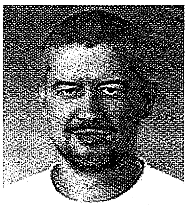

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