Evaluation of Selected Variants of Claddings on The Basis of CO_2 Production and Energy Intensity of Production of Building Materials

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***Abstract*— Wooden structures pollute the environment considerably less than the structures made of bricks, glass or concrete. Walls that use composite gypsum and cardboard-based materials and gypsum and cellulosic fibers-based materials for the interior surface of the walls have been selected for the evaluation of compositions of wooden claddings. Compositions using fiber gypsum boards were the most used for the construction of wooden structures in the Czech Republic in 2011 (CZSO – Czech Statistical Office). The main aim of the article is a comprehensive evaluation of wall panel with plasterboard (according to EN 520 - DFH2IR).**

Keywords*— *carbon dioxide; embodied energy; cladding; wooden structure

I. Introduction

Nowadays the demands for speed and quality of construction, and also for ecology in the entire wider environmental context are made when choosing a type of cladding. Wood is a natural material. It is the most promising raw material of the future. Wood is a renewable raw material which is fully recyclable and environment-friendly when it comes into being, during its use or recycling after the service life of the structure is exhausted. Carbon has long preserves in wood and wood products. This reduces the impacts on climate change. For example, 1 m^3 of wood retains up to 250 kg of CO_2. If the average consumption is 100 -150 m^3 of wood per a family house and the service life of the building is about 100 years, the amount of CO_2 is considerable.

A proposal of compositions of cladding of wooden structure is designed for the following types of wall construction, always in two material types-plasterboards and fiber gypsum boards: (1) Standard wall (a single wall), (2) Wall with a front wall, (3) Wall with a diffusion porosity structure.

II. Selection of Assessed Compositions of Cladding

The following material types of the composition are assessed in this article:

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A. *Walls using fiber gypsum boards*

Standard wall (single wall) is shown in Fig. 1 (type A). A wall with the front wall is shown in Fig. 2 (type B). A wall with the diffusion porosity structure is shown in Fig. 3 (type C).

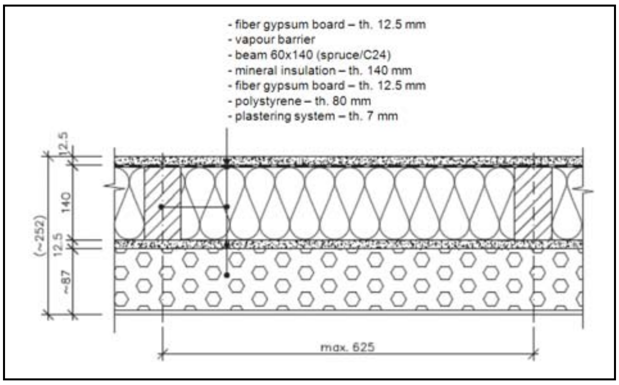

Fig. 1. Standard wall - single wall (author's archive).

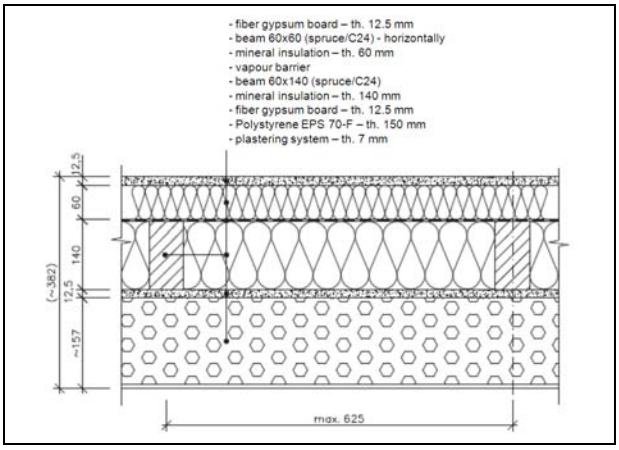

Fig. 2. A wall with the front wall (author's archive).

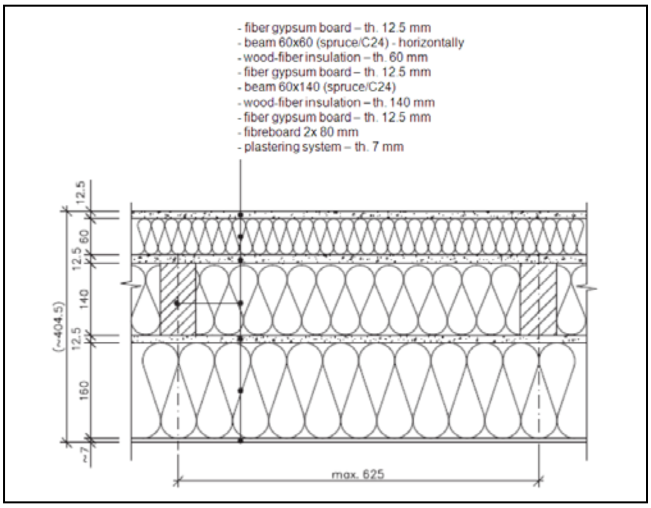

Fig. 3. A wall with the diffusion porosity structure (author's archive).

B. Walls Using Plasterboards (Board Type According to ČSN EN 520 - DFH2IR)

Standard wall (single wall) is shown in Fig. 4 (type D). A wall with the front wall is shown in Fig. 5 (type E). A wall with the diffusion porosity structure is shown in Fig. 6 (type F).

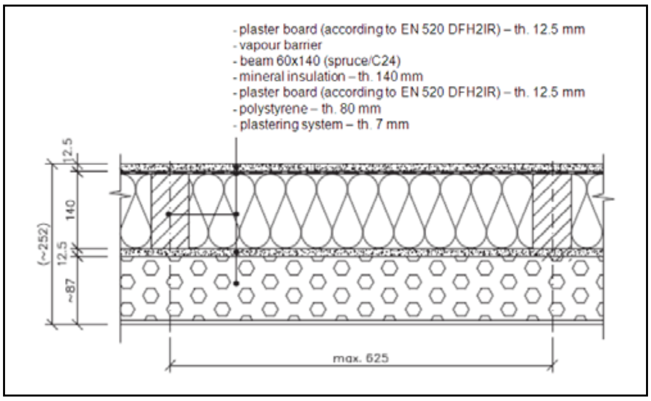

Fig. 4. Standard wall - single wall (author's archive).

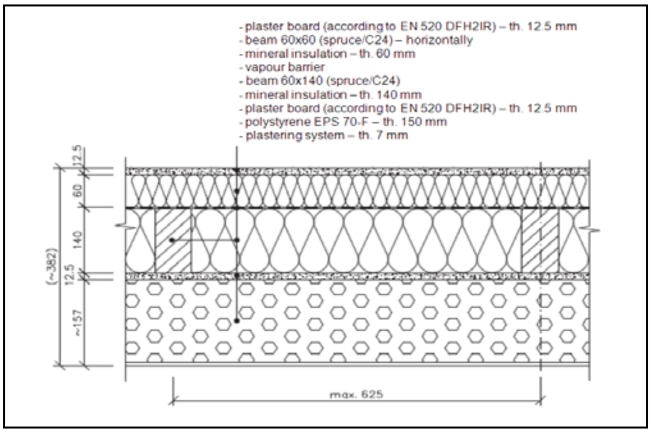

Fig. 5. A wall with front wall (author's archive).

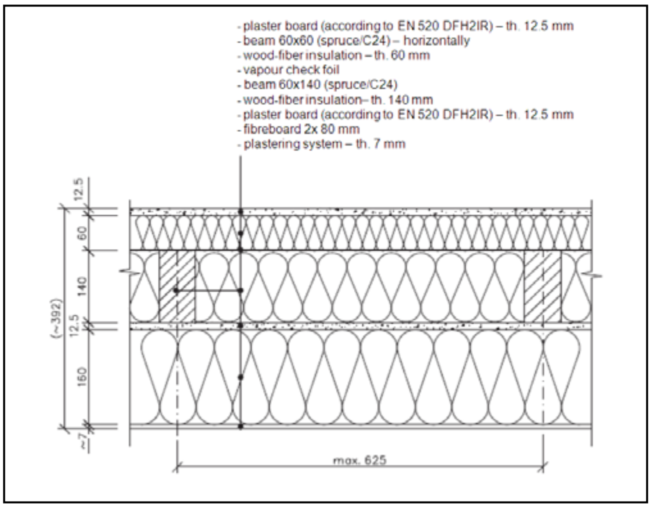

Fig. 6. A wall with the diffusion porosity structure (author's archive).

III. The Criterion of Energy Intensity of Production of Building Materials

Human activity significantly affects the environment. Production, transportation, building industry with its energetically-intensive products is among the major polluters of the environment. Officially presented results within the EU shows that building industry produces almost 30% of CO_2 emissions and consumes up to 40% of total energy.

There is dependency between higher energy consumption for the production of building materials and an increase in the amount of harmful emissions from industrial building production that are released into the atmosphere.

The environment is polluted mainly by burning fossil fuels in the production of building materials. The energy intensity of buildings increases to a large extent depending on the transport distance of raw materials and construction materials from the place of mining to the production site. Also, the transportation costs from the production site to dealers of building materials and the import of the product directly to the building site are not insignificant. Other demands for transportation are on the actual building site and they have also their own characteristics.

The best economical solution is to use local resources, such as local wood, sand etc. In this way, we can significantly reduce the costs including energy demands for construction.

Criterion LCA (life cycle assessment) is nowadays used for the evaluation of building materials in terms of energy consumption. Criterion LCA gives a more comprehensive view of the entire lifecycle of buildings including the environmental impact because it encompasses not only operating energy but also embedded energy. This criterion is getting to the fore in the assessment of buildings.

The total energy consumption and total CO_2 production per m^2 of cladding have been chosen as the most important criteria for the assessment of the energy demands for the production of cladding wooden structures. The amount of embodied energy for all types of cladding is shown in Table I – VI.

Energy demands are determined in accordance with the [1]:

$$E = \sum_{i=1}^{n} \varepsilon_i \cdot m_i \qquad (1)$$

where:

E: the amount of embodied energy for the product [MJ/m, MJ/m^2, MJ/pc],

ε_i: the amount of consumed energy for mining, production, and transportation of material [MJ/kg],

m_i: the weight of individual materials [kg/m, kg/m^2, kg/pc].

TABLE I. THE AMOUNT OF EMBODIED ENERGY FOR A STANDARD WALL (SINGLE WALL) USING FIBER GYPSUM BOARDS

Material	Quantity	Amount of consumed energy [1]	Amount of embodied energy
	kg/m²	***MJ/kg***	***MJ/m²***
Fiber gypsum board – th. 12.5 mm	14.75	3.80	56.05
Vapour barrier	0.17	714.00	121.38
Beam 60x140 (spruce/C24)	7.14	4.70	33.56
Mineral insulation – th. 140 mm	2.10	32.00	67.20
Fiber gypsum board – th. 12.5 mm	14.75	3.80	56.05
Polystyrene – th. 80 mm	1.28	95.00	121.60
Plastering system – th. 7 mm	4.80	1.50	7.20
Total amount of embodied energy for the structure of cladding			463.04

TABLE II. THE AMOUNT OF EMBODIED ENERGY FOR A WALL WITH FRONT WALL USING FIBER GYPSUM BOARDS

Material	Quantity	Amount of consumed energy [1]	Amount of embodied energy
	kg/m²	***MJ/kg***	***MJ/m²***
Fiber gypsum board – th. 12.5 mm	14.75	3.80	56.05
Beam 60x60 (spruce/C24) - horizontally	3.06	4.70	14.38
Mineral insulation – th. 60 mm	0.90	32.00	28.80
Vapour barrier	0.17	714.00	121.38
Beam 60x140 (spruce/C24)	7.14	4.70	33.56
Mineral insulation – th. 140 mm	2.10	32.00	67.20
Fiber gypsum board – th. 12.5 mm	14.75	3.80	56.05
Polystyrene EPS 70-F – th. 150 mm	2.40	95.00	228.00
Plastering system – th. 7 mm	4.80	1.50	7.20
Total amount of embodied energy for structure of cladding			542.19

TABLE III. THE AMOUNT OF EMBODIED ENERGY FOR A WALL WITH THE DIFFUSION POROSITY STRUCTURE USING FIBER GYPSUM BOARDS

Material	Quantity	Amount of consumed energy [1]	Amount of embodied energy
	kg/m²	***MJ/kg***	***MJ/m²***
Fiber gypsum board – th. 12.5 mm	14.75	3.80	56.05
Beam 60x60 (spruce/C24) - horizontally	3.06	4.70	14.38
Wood-fiber insulation – th. 60 mm	3.00	15.00	45.00
Fiber gypsum board – th. 12.5 mm	14.75	3.80	56.05
Beam 60x140 (spruce/C24)	7.14	4.70	33.56
Wood-fiber insulation – th. 140 mm	6.30	15.00	94.50
Fiber gypsum board – th. 12.5 mm	14.75	3.80	56.05
Fibreboard 2x 80 mm	33.60	15.00	504.00
Plastering system – th. 7 mm	4.80	1.50	7.20
Total amount of embodied energy for structure of cladding			796.36

TABLE IV. THE AMOUNT OF EMBODIED ENERGY FOR A STANDARD WALL (SINGLE WALL) USING PLASTERBOARDS

Material	Quantity	Amount of consumed energy [1]	Amount of embodied energy
	kg/m²	***MJ/kg***	***MJ/m²***
Plaster board – th. 12.5 mm	12.80	5.10	65.28
Vapour barrier	0.17	714.00	121.38
Beam 60x140 (spruce/C24)	7.14	4.70	33.56
Mineral insulation – th. 140 mm	2.10	32.00	67.20
Plasterboard – th. 12.5 mm	12.80	5.10	65.28
Polystyrene – th. 80 mm	1.28	95.00	121.60
Plastering system – th. 7 mm	4.80	1.50	7.20
Total amount of embodied energy for structure of cladding			481.50

TABLE V. THE AMOUNT OF EMBODIED ENERGY FOR A WALL WITH FRONT WALL USING PLASTERBOARDS

Material	Quantity	Amount of consumed energy [1]	Amount of embodied energy
	kg/m²	*MJ/kg*	*MJ/m²*
Plasterboard – th. 12.5 mm	12.80	5.10	65.28
Beam 60x60 (spruce/C24) - horizontally	3.06	4.70	14.38
Mineral insulation – th. 60 mm	0.90	32.00	28.80
vapour barrier	0.17	714.00	121.38
Beam 60x140 (spruce/C24)	7.14	4.70	33.56
Mineral insulation – th. 140 mm	2.10	32.00	67.20
Plaster board – th. 12.5 mm	12.80	5.10	65.28
Polystyrene EPS 70-F – th. 150 mm	2.40	95.00	228.00
Plastering system – th. 7 mm	4.80	1.50	7.20
Total amount of embodied energy for structure of cladding			551.42

TABLE VI. THE AMOUNT OF EMBODIED ENERGY FOR A WALL WITH THE DIFFUSION POROSITY STRUCTURE USING PLASTERBOARDS

Material	Quantity	Amount of consumed energy [1]	Amount of embodied energy
	kg/m²	*MJ/kg*	*MJ/m²*
Plaster board – th. 12.5 mm	12.80	5.10	65.28
Beam 60x60 (spruce/C24) - horizontally	3.06	4.70	14.38
Wood-fiber insulation – th. 60 mm	3.00	15.00	45.00
vapour check foil	0.17	714.00	121.38
Beam 60x140 (spruce/C24)	7.14	4.70	33.56
Wood-fiber insulation – th. 140 mm	6.30	15.00	94.50
Plasterboard – th. 12.5 mm	12.80	5.10	65.28
Fiberboard 2x 80 mm	33.60	15.00	504.00
Plastering system – th. 7 mm	4.80	1.50	7.20
Total amount of embodied energy for structure of cladding			870.92

The evaluation of selected claddings considering the amount of embodied energy shows that cladding types labeled F and C have the biggest energy consumption for the production of building product (see Fig. 7).

Thermal insulation based on wooden fibers is the reason of the high amount of embodied energy. Gypsum plasterboard additionally contributes to the largest energy consumption in case of the F type of cladding. Wood-fiber insulations consume only 15 MJ / kg of energy, but they occupy a substantial part due to its weight, which is in total 42.9 kg/m² in the structure of cladding. Gypsum plasterboard has more embodied energy than a fiber gypsum board; therefore all types of cladding with fiber gypsum board have less embodied energy. The type of cladding labelled A was evaluated as the best one considering the lowest amount of embodied energy per m².

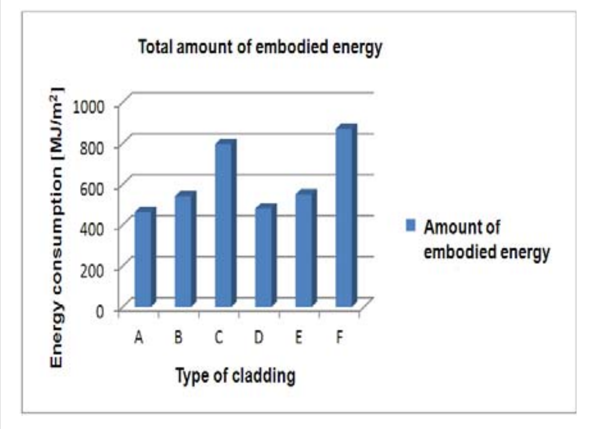

Fig. 7. Total amount of emgodied energy (author's archive).

IV. CO_2 PRODUCTION FOR THE PRODUCTION OF BUILDING MATERIALS

Greenhouse gases are considered one of the main causes of global warming. Carbon dioxide CO_2 has a major share of emissions of greenhouse gases, which is also produced during the industrial production of building components. The amount of released carbon dioxide for all types of cladding is shown in Table VII – XII.

TABLE VII. THE AMOUNT OF EMBODIED ENERGY FOR A WALL WITH THE DIFFUSION POROSITY STRUCTURE USING PLASTERBOARDS.

Material	Quantity	The amount of released carbon dioxide emissions [1]	CO_2 emissions of the product
	kg/m²	*kg/kg*	*kg/m²*
Fiber gypsum board – th. 12.5 mm	14.75	0.20	2.95
vapour barrier	0.17	36.00	6.12
Beam 60x140 (spruce/C24)	7.14	0.00	0.00
Mineral insulation – th. 140 mm	2.10	1.60	3.36
Fiber gypsum board – th. 12.5 mm	14.75	0.20	2.95
Polystyrene – th. 80 mm	1.28	2.30	2.94
Plastering system – th. 7 mm	4.80	0.20	0.96
Total CO_2 emissions of the cladding			19.28

Production of CO_2 is determined according to the [1]:

$$C = \sum_{i=1}^{n} \chi_i \cdot m_i \quad (2)$$

where:

C: carbon dioxide emissions of a product [kg/m, kg/m^2, kg/pc]

χ_i: amount of carbon dioxide released during mining, processing, production and transportation of material [g/kg]

m_i: weight of individual materials [kg/m, kg/m^2, kg/pc]

TABLE VIII. THE AMOUNT OF RELEASED CARBON DIOXIDE FOR A WALL WITH FRONT WALL USING FIBER GYPSUM BOARDS

Material	Quantity	The amount of released carbon dioxide emissions [1]	CO_2 emissions of the product
	kg/m^2	*kg/kg*	*kg/m^2*
Fiber gypsum board – th. 12.5 mm	14.75	0.20	2.95
Beam 60x60 (spruce/C24) - horizontally	3.06	0.00	0.00
Mineral insulation – th. 60 mm	0.90	1.60	1.44
vapour barrier	0.17	36.00	6.12
Beam 60x140 (spruce/C24)	7.14	0.00	0.00
Mineral insulation – th. 140 mm	2.10	1.60	3.36
Fiber gypsum board – th. 12.5 mm	14.75	0.20	2.95
Polystyrene EPS 70-F – th. 150 mm	2.40	2.30	5.52
Plastering system – th. 7 mm	4.80	0.20	0.96
Total CO_2 emissions of the cladding			20.35

TABLE IX. THE AMOUNT OF RELEASED CARBON DIOXIDE FOR A WALL WITH THE DIFFUSION POROSITY STRUCTURE USING FIBER GYPSUM BOARDS

Material	Quantity	The amount of released carbon dioxide emissions [1]	CO_2 emissions of the product
	kg/m^2	*kg/kg*	*kg/m^2*
Fiber gypsum board – th. 12.5 mm	14.75	0.20	2.95
Beam 60x60 (spruce/C24) - horizontally	3.06	0.00	0.00
Wood-fiber insulation – th. 60 mm	3.00	0.00	0.00
Fiber gypsum board – th. 12.5 mm	14.75	0.20	2.95
Beam 60x140 (spruce/C24)	7.14	0.00	0.00
Wood-fiber insulation – th. 140 mm	6.30	0.00	0.00
Fiber gypsum board – th. 12.5 mm	14.75	0.20	2.95
Fireboard 2x 80 mm	33.60	0.00	0.00
Plastering system – th. 7 mm	4.80	0.20	0.96
Total CO_2 emissions of the cladding			6.86

TABLE X. THE AMOUNT OF RELEASED CARBON DIOXIDE FOR A STANDARD WALL (SINGLE WALL) USING PLASTERBOARDS

Material	Quantity	The amount of released carbon dioxide emissions [1]	CO_2 emissions of the product
	kg/m^2	*kg/kg*	*kg/m^2*
Plasterboard – th. 12.5 mm	12.80	0.30	3.84
vapour barrier	0.17	36.00	6.12
Beam 60x140 (spruce/C24)	7.14	0.00	0.00
Mineral insulation – th. 140 mm	2.10	1.60	3.36
Plasterboard – th. 12.5 mm	12.80	0.30	3.84
Polystyrene – th. 80 mm	1.28	2.30	2.94
Plastering system – th. 7 mm	4.80	0.20	0.96
Total CO_2 emissions of the cladding			21.06

TABLE XI. THE AMOUNT OF RELEASED CARBON DIOXIDE FOR A WALL WITH FRONT WALL USING PLASTERBOARDS

Material	Quantity	The amount of released carbon dioxide emissions [1]	CO_2 emissions of the product
	kg/m²	*kg/kg*	*kg/m²*
Plaster board – th. 12.5 mm	12.80	0.30	3.84
Beam 60x60 (spruce/C24) - horizontally	3.06	0.00	0.00
Mineral insulation – th. 60 mm	0.90	1.60	1.44
vapour barrier	0.17	36.00	6.12
Beam 60x140 (spruce/C24)	7.14	0.00	0.00
Mineral insulation – th. 140 mm	2.10	1.60	3.36
Plasterboard – th. 12.5 mm	12.80	0.30	3.84
Polystyrene EPS 70-F – th. 150 mm	2.40	2.30	5.52
Plastering system – th. 7 mm	4.80	0.20	0.96
Total CO_2 emissions of the cladding			21.24

TABLE XII. THE AMOUNT OF RELEASED CARBON DIOXIDE FOR A WALL WITH THE DIFFUSION POROSITY STRUCTURE USING PLASTERBOARDS

Material	Quantity	The amount of released carbon dioxide emissions [1]	CO_2 emissions of the product
	kg/m²	*kg/kg*	*kg/m²*
Plaster board – th. 12.5 mm	12.80	0.30	3.84
Beam 60x60 (spruce/C24) - horizontally	3.06	0.00	0.00
Wood-fiber insulation – th. 60 mm	3.00	0.00	0.00
vapour check foil	0.17	0.20	0.03
Beam 60x140 (spruce/C24)	7.14	0.00	0.00
Wood-fiber insulation –th. 140 mm	6.30	0.00	0.00
Plasterboard – th. 12.5 mm	12.80	0.30	3.84
Fiberboard 2x 80 mm	33.60	0.00	0.00
Plastering system – th. 7 mm	4.80	0.20	0.96
Total CO_2 emissions of the cladding			4.83

Production of CO_2 emissions is evident in Fig. 8. The types of cladding labelled F and C have the smallest CO_2 emissions due to the use of wood-fiber insulations. Other types of cladding have CO_2 emissions many times higher.

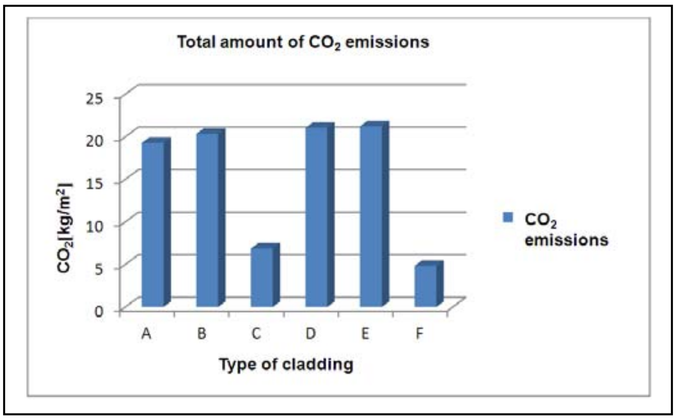

Fig. 8. Total amount of CO_2 emissions (author's archive)..

V. CONCLUSION

The total energy consumption and total CO_2 production per m_2 of wooden house cladding are the resulting criteria for the energy intensity of building materials production. There are only very slight differences between the structures with plasterboard and fiber gypsum board in terms of energy consumption and carbon dioxide emissions. Obvious differences in the high energy consumption and the low emissions of carbon dioxide are for cladding types C and F compared to other types of cladding. All this was caused by a change from mineral insulation to wood-fiber insulation.

From the selected structures of claddings and selected criteria, it is necessary to choose the best and optimal variant. The requirements and demands for cladding differ not only as for a complete structural element but also because each material has its advantages and disadvantages. Another problem is that not all of the required qualities are expressible by an exact value. Multi-criteria analysis method is one of the ways how to deal with the selection of optimal variant of building materials for the given purpose successfully. Multi-criteria analysis method is based on the requirements for building constructions and products defined by the Government Regulation no. 163/2002 Coll., on construction products (taken from the Council Directive on the approximation of laws and regulations of the EU concerning the qualities of construction products) [2].

REFERENCES

[1] J. Tywoniak, "Low-energy houses, principles and examples," Praha: Grada, pp. 200. (in Czech) , 2005.

[2] Government Decree no. 163/2002 Coll. dated March 6, 2002, which constitutes technical requirements for selected building products, as amended by Government Decree no. 312/2005 Coll. dated July 13, 2005. (in Czech)