NEARLY ZERO ENERGY BUILDING CO_2 EMISSIONS

DOI: 10.18485/arh_pt.2020.7.ch29

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ABSTRACT

Nearly zero energy standard is an obligation for all new buildings in the European Union since the beginning of the year 2020. Improved energy efficiency and the transition from fossil fuels to renewable sources are expected to significantly reduce CO_2 emissions from buildings. Operational energy (for heating, domestic hot water, cooling etc.) represents a large share of the energy use in buildings, but it is still only a segment in overall energy use during the life cycle of a building. Another major share is construction and production of building materials. For the buildings with the poor energy performance and fossil fuels as the main energy source, overall operational energy CO_2 emissions exceed embodied energy emissions by several times. As energy sources shift from fossil fuels to renewable energy, operational and embodied energy ratio is changing.

This article compares operational energy CO_2 emissions for buildings that meet the nearly zero energy standards with those that do not, as well as embodied energy CO_2 emissions for the different types of load bearing construction. Analysis is performed on a single-family house in Zagreb, Croatia, that meets the current national standards. Operational energy CO_2 emissions comparison is made for: standard natural gas boiler, condensing natural gas boiler combined with photovoltaic solar panels, air to water heat pump and wood pellets boiler. Embodied energy CO_2 emissions comparison is made for: reinforced concrete walls and slabs, perforated brick walls with semi-prefabricated ceiling and timber frame construction.

KEYWORDS _ *nearly zero energy building, CO_2 emissions, operational energy, embodied energy, single-family house*

INTRODUCTION

Major changes are occurring in the building sector. From 2020, the Nearly Zero Energy Building (nZEB) Standard will be required for all new buildings. Improved energy efficiency and the transition from fossil fuels to renewable sources are expected to reduce significantly CO2 emissions from buildings.

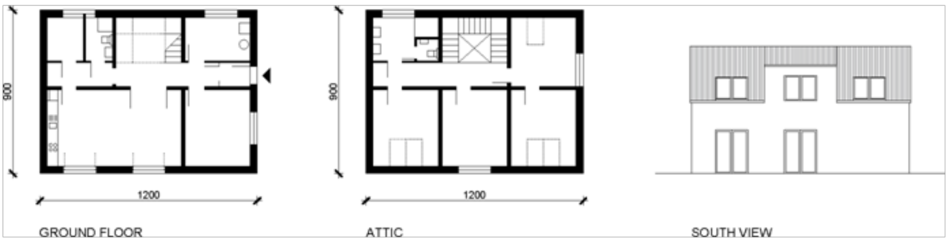
Directive 2010/31/EU on the energy performance of buildings (EPBD II) lays down the obligation that after 31 December 2019, all new buildings should be nearly zero-energy buildings, meaning they should be highly energy efficient, and their energy demand should largely be met from renewable energy sources. As an EU member state, Croatia has honoured its obligation of establishing the nearly zero-energy building standard and has laid down requirements in the document titled *Technical regulation on energy economy and heat retention in buildings* (Official Gazette 128/2015) which has been in effect since 1 January 2016[1]. The Technical Regulation sets the same deadline for design of nearly zero-energy buildings, which is 31 December 2019. After that date, all new buildings need to be nearly zero-energy.

In December 2019, there were 850 building permits issued. By types of constructions, 83,2% of permits were issued on buildings (80% residential buildings, 20% non-residential buildings) and 16,6% on civil engineering works. By types of construction works, 75,3% of permits were issued on new construction and 24,7% on reconstruction[2]. Considering these statistics, the residential building sector dominates construction activity in Croatia, so many studies on the future building standards have primarily been focused on residential buildings.

The paper is the results of a research and development project on "Sustainable construction in Croatia"[3] . It also refers to a students' research "CO2 footprint of nearly-zero energy buildings" undertaking for the course Architecture & Technology 1 (2018/2019) within the master degree programme at the Department of Architectural Technology and Building Science, Faculty of Architecture, University of Zagreb[4].

ANALYSED MODEL OF A SINGLE-FAMILY HOUSE

For the purpose of this paper, the model of the family house is a single-family house in Zagreb (continental part of Croatia). It is a 172 m^2 two-storey building with perforated brick walls, semi-prefabricated ceiling and timber roof construction. Outer walls are thermally insulated with 15 cm polystyrene, floor to the earth with 12 cm polystyrene and pitched timber roof with 21 cm mineral wool. Openings are double glazed with plastic frames. The house is ventilated naturally (by windows).



_ Figure 1. Plans and view of a model of a single-family house

In such a building the calculated results are: the specific annual energy need for heating is Q"H,nd = 38 kWh/m2a, the annual energy need for heating is QH,nd = 6.553 kWh/a, and the QW,nd 2.150 kWh/a for domestic hot water. The analysis was done in line with the current Technical Regulation and with the use of EnCert-HR v.2.42 software.

1 *** 2015.
2 Croatian Bureau of Statistics. 2020.
3 Veršić, Z. et. al. 2019.
4 Muraj, I., Veršić, Z., & Binički, M. 2020.

OPERATIONAL ENERGY CO2 EMISSIONS

In continental parts of Croatia, as well as in most of Europe, energy use for space and domestic hot water heating is the most important end-use in the residential sector. According to Technical regulation annual primary energy and CO2 emission calculation for residential buildings includes only the energy for heating, domestic hot water and auxiliary energy for ventilation system (if installed) . In this analysis only CO2 emissions for heating and domestic hot water (in further text DHW) are calculated, while the energy for lighting and household appliances is estimated. CO2 emissions will evenly depend on the energy need, type of fuel and system efficiency. 1 kWh of heat from biomass will produce more CO2 than 1 kWh of heat from natural gas[6], as well as 1 kWh of produced electrical energy. But on the global scale, growing biomass will absorb CO2 from the atmosphere and use of highly efficient electrical heat-pump heating will result in less CO2 emissions.[7] Fuel CO2 emissions are calculated as a global warming potential (in further text GWP), as a factor of carbon dioxide, or CO2 equivalent (in further text CO2 eq).
This analysis will include heating systems that meet the nearly zero energy standards (obligation since the beginning of the year 2020) and those that do not (before year 2020) for a building with the same energy need (QH,nd = 6.553 kWh/a). For a nearly zero energy single-family house in continental Croatia, annual specific primary energy need Eprim/Ak for heating and DHW should not exceed 45 kWh/m2a, and renewable energy ratio γren should be greater than 30%. For the analysed cases, the same system is used both for heating and DHW.

_ Table 1: Basic heating and DHW system information and fuel CO2 emissions

Heating and DHW system	Overall system efficiency* η_{system} (-)	Fuel	Primary energy factor** f_{del} (-)	GWP_{fuel}/kWh** (kg CO_2 eq/kWh)
Standard boiler	0,72	Natural gas	1,095	0,220
Condensing boiler	0,81	Natural gas	1,095	0,220
Photovoltaic panels	0,15	Electricity	-1,614	-0,235
Air-water heat pump	2,55	Electricity	1,614	0,235
Wood pellets boiler	0,81	Wood pellets	0,123	0,034

* average values for a type of a heating system
** national fuel primary energy factors and CO_2 emissions per kWh of energy

Annual primary energy consumption of a system is calculated from delivered energy and primary energy factor:

Edel = Eneed / ηsystem

Eprim = Edel . fdel

Where

Edel is the delivered energy to a system (kWh);
Eneed is the energy need of a system (kWh);
Eprim is the primary energy of a system (kWh);
ηsystem is the system efficiency (-);
fdel is the nationally defined primary energy factor of a delivered energy carrier (-)

Renewable energy share is calculated by the formula:[8]

γren = 100 . (Eren + Eren1) / (Eren + Edel,total)

Where

Eren is the renewable energy produced on site (solar and environment energy) (kWh);

5 *** 2015.
6 Sterman, J. D., Siegel, L., & Rooney-Varga, J. N. 2018.
7 *** 2020.
8 Kurnitski, J. (Ed.). 2013.

Eren1 is the renewable energy delivered to the building (biofuel, biomass…) (kWh);
Edel,total is the total energy delivered to the building (kWh);
γren is the renewable energy share in the delivered energy (%)

_ Table 2: Nearly zero energy building criteria and results for different heating and DHW systems in the analysed model of a 172 m2 single-family house and CO2 emissions from annual energy use

Heating, DHW system	Fuel	E_{prim}/A_k (kWh/m^{2}a)	Renewable energy share γ_{ren} (%)	nZEB	$GWP_{heating,DHW}$ (kg CO_2 eq/a)	GWP_{total} (kg CO_2 eq/a)
1. Standard gas boiler	Natural gas	76,60	0%	**No**	**2.659**	**3.451**
2. Condensing gas boiler & PV panels	Natural gas Electricity	34,31	30%	**Yes**	**1.536**	**2.328**
3. Air-water heat pump	Electricity	32,03	67%	**Yes**	**785**	**1.577**
4. Wood pellets boiler	Wood pellets	7,68	100%	**Yes**	**370**	**1.162**

With the transfer from fossil to renewable energy sources, reduction in CO2 emissions for heating and DHW of a single-family house range from 42% to 86%. If energy consumption for other systems and appliances is included, then emissions savings ratio is smaller. Annual use of electricity for lighting and other household appliances is estimated to 3.600 kWh/a[9], which will result in additional CO2 emissions of 792 kg CO2. When electricity use for lighting and other household appliances is accounted, transfer to nearly zero energy standard reduces operational energy CO2 emissions from 33% to 66% annually.

EMBODIED ENERGY CO2 EMISSIONS

Overall weight of materials in the analysed single-family house equals 290 tons. Production of such great amount of materials requires energy and therefore releases CO2. Depending on the material, production emissions can vary from negative values to notable amounts in worldwide emissions. Wood products store more carbon than it is released from their manufacture[10], resulting in negative CO2 emissions. On the other hand, in the last 20 years, global cement production has doubled, and emissions from cement production reached 1,5 Gt CO2 in 2014[11], or 4% of emissions from fossil fuels, and 8% of total CO2 emissions.
The impact of the material production on the environment can be measured as a GWP in the same way as a GWP for greenhouse gasses. Material total GWP (GWPtotal) includes both contributions of greenhouse gasses to the atmosphere as well as carbon stored in the material. Since the production process differs for each manufacturer and country (type of fuel used, national electricity production emissions etc.), CO2 emissions for the same product also differ. Materials CO2 emissions in this analysis were obtained from baubook eco2soft – life cycle assessment of the buildings software. The calculation of material GWPtotal is according to ÖNORM EN 15804.

_ Table 3: Global warming potential GWPtotal,material (kg CO2 eq) of the materials and layers used in the example

Material (function)	$GWP_{total,material}$ (kg CO2 eq/kg)	Density ρ (kg/m^3)	Thickness in construction d (cm)	CO_2 emission/m^2 (kg CO_2 eq/m^2)
Cement screed	**0,120**	2000	6	**14,4**
Clay roof tiles	**0,258**	2000	2	**10,3**

9 Brounen, D., Kok, N., & Quigley, J. M. 2012.
10 Lippke, B., Wilson, J., Meil, J., & Taylor, A. 2010.
11 Andrew, R. M. 2018.

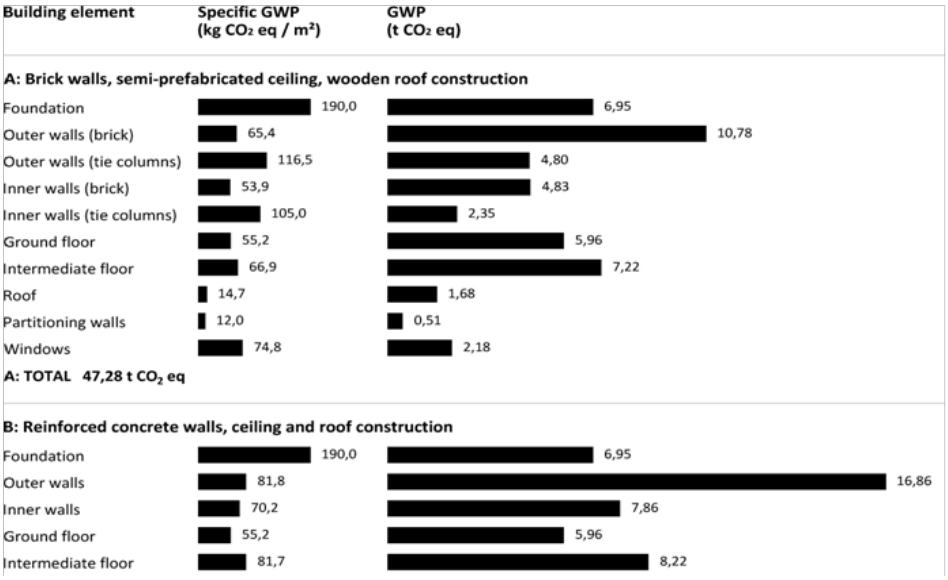
Concrete (foundation)	**0,095**	2000	100	**190,0**
Concrete (slab)	**0,095**	2000	10	**19,0**
EPS 150 (ground floor insulation)	**4,170**	27,5	10	**11,5**
EPS f (wall insulation)	**4,170**	15,8	15	**9,9**
EPS t (soundproofing)	**4,170**	11	2	**0,9**
Gypsum board	**0,226**	900	2,5	**5,1**
Laminated timber (walls/slabs)	**-1,100**	475	16	**-83,6**
Mineral wool (roof insulation/soundproofing)	**2,450**	15	21	**7,7**
OSB board	**-1,150**	650	1,8	**-13,5**
Perforated brick (wall)	**0,182**	1000	25	**45,5**
Perforated brick (semi-prefabricated ceiling)	**0,193**	1125	15	**32,6**
Plastering mortar	**0,155**	1800	1,5	**4,2**
Polyethylene (vapor brake)	**2,630**	650	0,02	**0,3**
Polyethylene (roof underlay)	**3,300**	980	0,02	**0,6**
Polyethylene (sealing sheeting)	**2,100**	980	0,02	**0,4**
Polymer bitumen (waterproofing)	**0,819**	1100	1	**9,0**
Reinforced concrete (walls/slabs)	**0,161**	2400	16	**61,8**
Silicate plaster (rendering)	**0,651**	1800	0,5	**5,9**

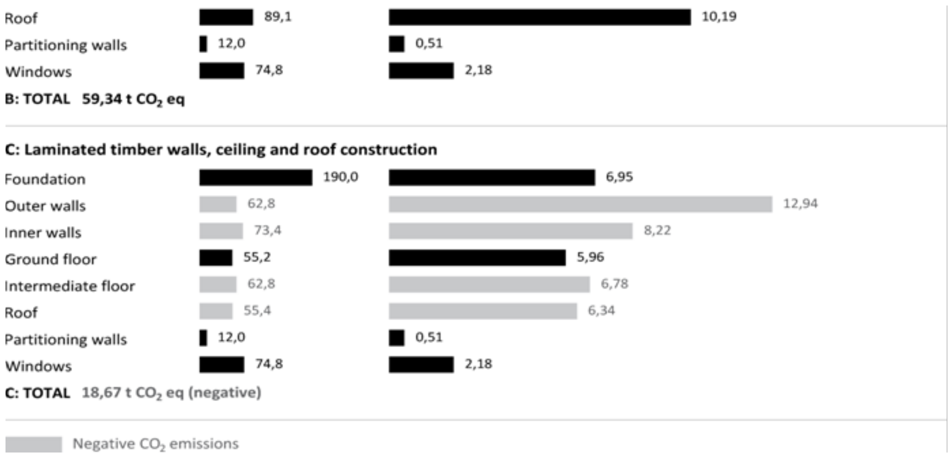
$GWP_{total,material}$ (kg CO_2 eq/kg) data from *baubook eco2soft – life cycle assessment of the buildings* software. The calculation of material GWP_{total} according to ÖNORM EN 15804.

GWPtotal,material (kg CO2 eq/kg) data from baubook eco2soft – life cycle assessment of the buildings software. The calculation of material GWPtotal according to ÖNORM EN 15804.

GWP value of each layer must be compared in combination with density and thickness, and therefore mass. Production of thermal insulation materials emits most of CO2 per kg of material, while the lowest emissions are per kg of concrete. However, the concrete wall is hundreds of times heavier than the thermal insulation in construction, and therefore the final greatest emissions are from load bearing construction, and the lowest from thermal insulation and other linings.

Further analysis will compare operational energy emissions with those of embodied energy. Three types of load bearing construction with accompanying linings will be calculated: masonry, reinforced concrete and laminated timber. Thermal insulation thickness remains the same in all the cases. Due to the changes in thermal conductivity of load bearing construction, the changes in operational energy are less than ±1%, and they are neglected in further analysis.



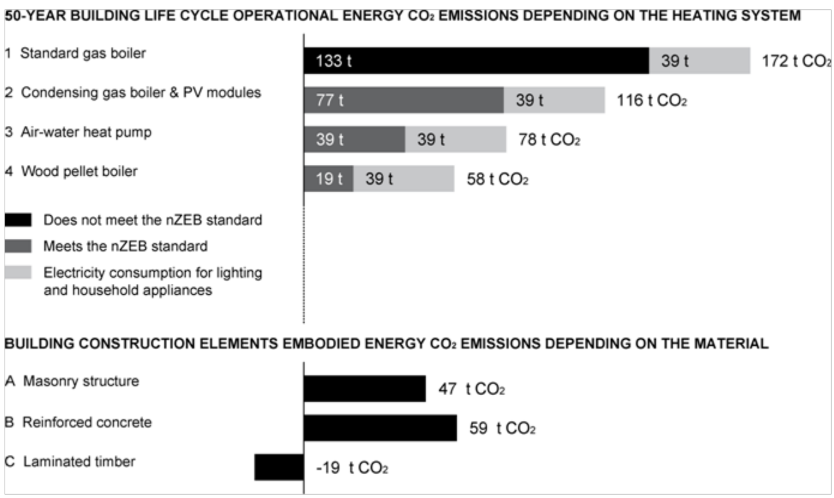


_ Figure 2: Construction elements embodied energy CO2 emissions for a model of a single-family house

RESULTS

Expected lifetime of a building is 50 years (for the load bearing construction). That is the time frame inside which embodied and operational energy will be compared. Building elements refurbishment as well as decline in heating and DHW system efficiency are neglected in the calculation. Due to the changes in thermal conductivity of load bearing construction, the changes in operational energy are less than ±1%, and they are also neglected in further analysis.

For fossil fuel heating systems, building lifetime CO2 emissions (for heating, DHW and electricity) are several times greater than those of embodied energy. In case of old buildings (with poor energy efficiency) that ratio is much greater. Nearly zero energy standard and transfer to renewable energy sources reduces operational energy CO2 emissions (for heating, DHW and electricity use) from 33% to 67% for the analysed single-family house. With such reduction in building heating and DHW emissions, operational energy is reduced to a scale of embodied energy.



_ Figure 3: 50-year building life cycle operational and embodied energy CO2 emissions (t CO2 eq)

CONCLUSIONS

Results show that nearly zero energy standard significantly reduces operational energy CO2 emissions and that further potential for reducing carbon dioxide emissions lies in the choice of building materials. The emphasis is on a load bearing construction since it is the source of most embodied energy CO2 emissions. Since the timber sequesters large amounts of carbon, it has a negative CO2 footprint, and the reinforced concrete structure the highest due to cement production emissions. Although wooden constructions products impact environment the least, flammability and load bearing capacity are the limiting factor in their use. The same characteristics of reinforced concrete are the reason for its' widespread use.

Single family houses are the least challenging type of buildings regarding load bearing construction and fire protection, the choice of negative or low CO2 footprint materials is possible for most of the building layers and elements. For other, more demanding types of buildings, such choice may not be possible for all elements, but if it is considered timely, the reduction in embodied CO2 emissions can also be achieved.

REFERENCES

- Andrew, R. M. 2018. "Global CO2 emissions from cement production". *Earth System Science Data* 10, no. 1 (January): 195.
- Brounen, D., Kok, N., & Quigley, J. M. 2012. "Residential energy use and conservation: Economics and demographics". *European Economic Review* 56, no. 5 (January): 931-945.
- Croatian Bureau of Statistics. 2019. "Building Permits Issued, December 2019, First release". Accessed February 12, 2020. https://www.dzs.hr/.
- Kurnitski, J. (Ed.). 2013. *Cost optimal and nearly zero-energy buildings (nZEB): definitions, calculation principles and case studies*. Springer-Verlag London.
- Lippke, B., Wilson, J., Meil, J., & Taylor, A. 2010. "Characterizing the importance of carbon stored in wood products". *Wood and Fiber Science* 42 (March): 5-14.
- Muraj, I., Veršić, Z., Binicki, M. 2020. "Sustainability, Environmental Performance and Energy Efficiency in Higher Education: Faculty of Architecture, University of Zagreb". In *IOP Conference Series: Earth and Environmental Science* (Vol. 410, No. 1, p. 012088). IOP Publishing.
- Sterman, J. D., Siegel, L., & Rooney-Varga, J. N. 2018. "Does replacing coal with wood lower CO2 emissions? Dynamic lifecycle analysis of wood bioenergy". *Environmental Research Letters* 13, no. 1 (January): 015007
- Veršić, Z. et al. 2019. "Determining a model of reference public buildings from different periods of construction in Croatia for the purpose of energy analysis refurbishment into nearly zero-energy buildings (nZEB)". Scientific project, Faculty of Architecture, Zagreb, 2017-2019.
- *** Republic of Croatia, Ministry of Construction and Physical planning. 2020. "Primary energy factors". Accessed March 5, 2020. https://mgipu.gov.hr/.
- *** Technical regulation on energy economy and heat retention in buildings (OG 128/2015)

SOURCES OF ILLUSTRATIONS

- Figures 1 – 3 Authors

SOURCES OF TABLES

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