https://doi.org/10.1051/e3sconf/202234904014

The use of green roofs to improve wooden buildings for a future bioeconomy

Birgit Brunklaus[1*], *Jutta* Schade[2], and *Jani* Mukkavaara[3]

[1]RISE, Research Institute of Sweden, Division of Built Environment, Department of System Transition and Service Innovation, Unit of Energy and Environmental Systems Analysis, 41258 Gothenburg, Sweden.
[2]RISE, Research Institute of Sweden, Division of Built Environment, Department of Building and Real Estate, Unit of Building Envelope and Building Physics, 50115 Borås, Sweden.
[3]LTU, Luleå University of Technology, Division of Industrialized and Sustainable Construction, Department of Civil, Environnemental and Natural Ressources Engineering, 97187 Luleå, Sweden.

Abstract. Bioeconomy helps to move towards a renewable, fossil-free future. The environmental impact is significantly reduced when replacing fossil-based products with bio-based alternatives. In a bioeconomy, all products are made from renewable and biogenic resources. In the building sector examples for biogenic sources are traditionally wooden building structures, while green roofs are becoming more popular. The goal of the present project was to assess the amount of biogenic carbon stored in green roofs and wooden buildings overall. The question is whether green roofs are improving the biogenic carbon usage of buildings and find out how that can be improved. The methods used are based on construction modelling, life cycle assessment and standardised environmental product declaration (EPD). The results indicate that wooden building structures are not enough for a complete biogenic building to move to a renewable, fossil-free future. Furthermore, the green roofs do add more biogenic carbon to the building than conventional roofs, while seen over the whole building these benefits are negligible. The results are presented as renewable and non-renewable energy as well as biogenic carbon and greenhouse gas emissions. These are compared with conventional roofing based on non-renewable standard roofs in Sweden.

1 Introduction

Bioeconomy helps to move towards a renewable, fossil-free future. The bioeconomy covers all kinds of products: energy, biofuel, heat, construction, bioplastics, textiles, and pharmaceuticals. In the Nordic Countries, the environmental impact is significantly reduced when replacing energy products made from fossil resources with bio-based alternatives, for example bio-based fuels reduce carbon emissions by 85%, while also bio-based solutions in construction reduces carbon emissions by 50% [1].

* Corresponding author: birgit.brunklaus@ri.se

In a bioeconomy, all products are made from renewable and biogenic resources. In the building sector, examples for biogenic materials are traditionally wooden building structures, while green roofs are becoming more popular. The goal of the present project was to assess the amount of biogenic carbon stored in green roofs and wooden buildings overall. The question is whether green roofs are improving the biogenic carbon usage of buildings and find out how that can be improved. The methods used are based on construction modelling, life cycle assessment and standardised environmental product declaration (EPD).
This article summarizes the main results of the biogenic carbon study of the project so far. The goal & scope are described in section 1, the methods and data collection in section 2, the result of the comparison is presented and discussed in sections 3 and 4 respectively, and the conclusion is presented in section 5.

2 Methods and data collection

Within the research project, a digital framework for sustainable design has been applied to an existing wooden building in the North of Sweden, and the data have been collected from the first passive house above the Polar Cycle built 2016 in the North of Sweden (Fig 1).

Fig. 1. Wooden building – Passive House in Northern Sweden (7de huset)

The project started in February 2019 and has since gathered data through on-site observations of different roof alternatives in the North of Sweden, personal communication with green roof producer Vegtech, green roof experts and representative from the building sector on a green roof workshop, as well as a literature review on life cycle data on green roofs and building construction data specific for the passive house in the North of Sweden.

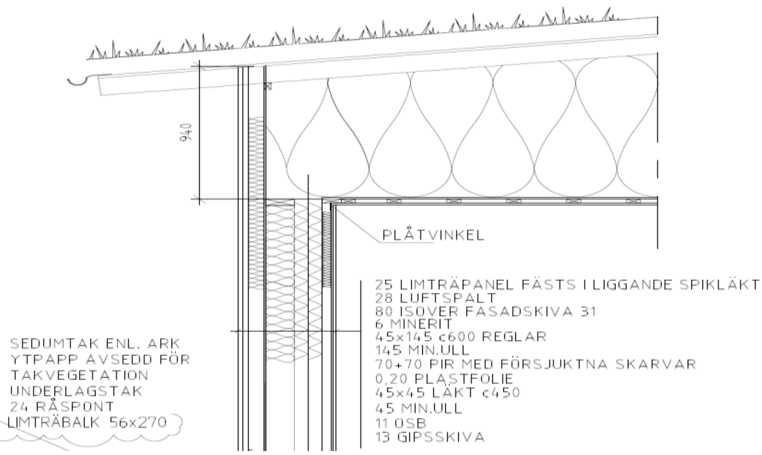

Fig. 2. Wooden building – Passive House in Northern Sweden (7de huset, cross section)

2.1 Biobased wooden building - Passive house in Northern Sweden

The biobased wooden building is a semi-detached passive house (for two households) with a living area of 302m^2 and a green roof area of 204 m^2, see figure 1. The insulation of the roof is 1000 mm loose fill mineral wool and a calculated U-value of 0.033 W/m^{2}K, which is much higher dimensioned than a standard roof for the subarctic climate [2]. In the south of Sweden, Lindås in Gothenburg the first Swedish passive house been built with the 500 mm mineral wool isolation and U-value for the roof of 0.08 W/m^{2}K [3]. The cross section of the construction is found in figure 2. The data collection for the materials is presented in table 1.

Table 1. Data collection for the roof, walls, and beans (grey for wooden based data)

	Data Collection for the materials	**Length (m)**	**Area (m^2)**	**Volume (m^3)**
Green roof	Green roof (Extensive), (Sedum layer 30mm, textile layer 10 mm and waterproof layer 10 mm)		203.2	10.2
Building element - Roof	Grooved Wooden Board 22x120 mm	1693.3	203.2	4.5
	Roof Wooden trusses (16 pieces)			4.3
	Loose-fill wool (insulation) 1000 mm		175.9	175.9
	Cellular plastic (insolation) 0.2 mm		450.5	0.1
	Wooden panel 28x70 mm	495.7	69.4	1.9
	Plaster Board (Gypsum) 13 mm		1102.6	15.7
	Plaster Board (Gypsum) 15 mm		148.7	2.2
Buildings Element - Outside Wall	Glulam Wooden Panel 25x225 mm	1240.9	279.2	7.0
	Wooden Nail Lath 28x70 mm	465.3	32.6	0.9
	Isover Facade Board (insolation) 31 80 mm		279.2	22.3
	Minerit (Cement) 8 mm		279.2	2.2
	Wooden Latches 45x145 mm	457.7	20.6	3.0
	Mineral Wool (insolation) 145 mm		254.0	36.8
	Thermal board of Polyisocyanurate (PIR) (insolation) 70+70 mm		274.6	38.4
	Wooden Latches 45x45 mm	610.2	27.5	1.2
	Mineral Wool (insulation) 45 mm		384.7	17.3
	Wooden Board OSB 11 mm		376.0	4.1
Middle Beams	Floor Chip Board 22 mm		148.7	3.3
	Wooden Masonite Latches 45x220 mm	269.6	12.1	2.7
Ground Beams	Concrete 100 mm		175.9	17.6
	Cellular Plastic 4x100 mm		175.9	70.4
Building element Inner Wall	Wooden Latches 45x120 mm		11.4	1.4
	Stone Wool (insulation) 145 mm		90.0	13.0
	Wooden Latches 45x70 mm	357.7	16.1	1.1
	TOTAL amount of area and volume		**5191.1**	**457.5**

The results of data collection in table 1 show that the whole building accounts for a material area of 5191.1 m^2 and a volume of 457.5 m^3. The most important data are the green roof, the wooden material, the gypsum/concrete, and the insulation material. Even though the green roof covers a large area (203 m^2), the amount of green roof is quite small (10.2 m^3 and only 2.2% of the volume of the whole building). Even though many wooden materials are included, the amount is not large (35.4 m^3 and only 7.8% of the volume of the whole building). Similar results are for gypsum/concrete materials (37.7 m^3 and 8.2% of the volume of the whole building). Surprisingly, the insulation materials do have the most share of the material (374.2 m^3 and 81.8% of the volume of the whole building).

2.2 Impact categories - energy and climate change

The impact categories chosen are energy (renewable energy demand RED, non-renewable energy demand NRED, and total energy demand ED) and climate change (Global Warming Potential GWP, including greenhouse gas emissions GWP-GHG and biogenic carbon GWP-BIO stored in the green roof and the materials used in the building). 'Embodied carbon' is a term widely used in the construction sector. It is the sum of all greenhouse gas emission (GHG) in the making of a building [4]. In this study, the focus is on biogenic carbon stored in green roofs and the materials used in wooden buildings. The data collected are based on available environmental product declarations (EPD) based on lifecycle assessment (LCA). The chosen system boundaries include only the production data of the materials (A1-3), since the goal of the project was to assess the amount of biogenic carbon stored in green roofs and wooden buildings. The LCA/EPD data of important materials are presented in table 2.

Table 2. EPD data (A1-3) for main materials: energy (RED, NRED) and GWP (incl. biogenic carbon)

LCA/EPD	Energy (RED, NRED, ED)	Global Warming Potential (GWP, GWP-GHG, GWP-BIO)
LCA Green roof Sweden	RED = 31 MJ/m^2 NRED = 124 MJ/m^2 TOTAL ED = 155 MJ/ m^2 (20% renewable energy)	GWP-GHG = 3.21 kg CO_2eq / m^2 GWP-BIO = 4.82 kg CO_2eq / m^2 TOTAL GWP = 8.03 kg CO_2eq / m^2 (60% biogenic carbon)
EPD Wooden materials Sweden	RED = 9910 MJ/ m^3 NRED = 748 MJ/ m^3 TOTAL ED = 10 658 MJ/ m^3 (93% renewable energy)	GWP-GHG = 138 kg CO_2eq / m^3 GWP-BIO = - 715 kg CO_2eq / m^3 TOTAL GWP = - 577 kg CO_2eq / m^3 (84% biogenic carbon)
EPD Gypsum and concrete materials	RED = 194 MJ/ m^3 NRED = 1115 MJ/ m^3 TOTAL ED = 1309 MJ/ m^3 (15% renewable energy)	GWP-GHG = 251 kg CO_2eq / m^3 GWP-BIO = 0 kg CO_2eq / m^3 TOTAL GWP = 251 kg CO_2eq / m^3 (0% biogenic carbon)
EPD Insolation material (mineral wool)	RED =71.8 MJ/ m^3 NRED = 941 MJ/ m^3 TOTAL ED = 101.8 MJ/m^3 (7 % renewable energy)	GWP-GHG = 76.7 kg CO_2eq / m^3 GWP-BIO = 0 kg CO_2eq / m^3 TOTAL GWP = 76.7 kg CO_2eq / m^3 (0% biogenic carbon)
EPD Insolation material (stone wool)	RED = 71.3 MJ/ m^3 NRED = 461 MJ/ m^3 TOTAL ED = 532.3 MJ/ m^3 (13 % renewable energy)	GWP-GHG = 49.5kg CO_2eq / m^3 GWP-BIO = 0 kg CO_2eq / m^3 TOTAL GWP = 49.5 kg CO_2eq / m^3 (0% biogenic carbon)
EPD Insolation material (loose wool)	RED = 663 MJ/ m^3 NRED = 80.2 MJ/ m^3 TOTAL = 743.2 MJ/ m^3 (13 % renewable energy)	GWP-GHG = 37.1 kg CO_2eq / m^3 GWP-BIO = 0 kg CO_2eq / m^3 TOTAL GWP = 37.1 kg CO_2eq / m^3 (0% biogenic carbon)

3 Results of the wooden building and green roofs in comparison

The results are presented for the wooden building (table 3) and the roofing systems (table 4). The results are presented as energy (renewable and non-renewable energy) as well as climate change (biogenic carbon and GHG emissions). The green roofing system is compared with conventional roofing systems based on standard roofs in Sweden.

Table 3. Wooden building (A1-3), energy (RED, NRED) and climate change (biogenic and GHG)

Total building	**Energy Climate change**	**Energy Climate change**	**TOTAL**
MJ/FU	121 347 MJ (RED)	114 904 MJ (NRED)	1 478 390 MJ
Kg CO_2eq/FU	- 23 854 kg (Biogenic carbon)	40 256 kg (GHG emissions)	16 486 kg (Climate change)

The results in table 3 show that the GHG emissions of the total building accounts for 40.2 t CO_2eq and the biogenic carbon from the wooden products in the buildings accounts for 60% (23.8 t CO_2eq). Also, the green roofing system accounts for 60% biogenic carbon (table 4). Even though green roofing systems include more biogenic carbon (60%) than other conventional roofing system (0-19% biogenic carbon), the results in table 4 also show that the green roofing system accounts for only 5% (1.9 t CO_2eq) of the buildings climate change (40.2 t CO_2eq). These results indicate that this is neither enough for a complete biogenic building nor enough to move to a renewable, fossil-free future. The remaining GHG emissions come from the insulation (19.3 t CO_2eq), the concrete/gypsum (9.6 t CO_2eq), the wood construction (5.9 t CO_2eq), as well as the large number of windows (22 windows account for 5.5 t CO_2eq).

Table 4. Roofing systems (A1-3), climate change and biogenic carbon

Roofing system	**Climate change (Kg CO_2eq)**	**Biogenic carbon (%)**
Green roof	1906	60% biogenic carbon
Conventional roof (Coated steel roof, Asphalt roll roof, Concrete tile roof, Clay tile roof)	2825, 622, 1942, 3374	0-19% biogenic carbon (14%, 0%, 19%, 12%)

4 Discussing insulation, energy, maintenance, new standards

Here we will discuss the insulation thickness, the energy factors, the maintenance, and new standard in climate declaration. More **insulation** is needed in the Northern Sweden. Instead of 500 mm mineral wool isolation in the south of Sweden and a U-value of 0.08W/m^{2}K, in the Northern Sweden, there is 1000 mm loose fill mineral wool needed with a U-value of 0.033 W/m^{2}K. What does that mean for climate impacts? The climate impacts for roof insulation are around 6526 kg CO_2eq. That means 50% (326.9 kg CO_2eq) less is needed in the Southern Sweden. That is about 8% less of the total amount (40 256 kg CO_2eq).
The **energy factors** are different for the Northern and the Southern Sweden (kWh/m^2). The district heating in the cities of Sweden depend on the source of energy and the results are quite different. For example, the cities in Southern Sweden: Gothenburg (52g CO_2eq/kWh), Stockholm (66g CO_2eq/kWh), Malmö (130g CO_2eq/kWh) and in the Northern Sweden: Kiruna (107g CO_2eq/kWh), based on emission factors for district heating in Sweden [5].

The **operation and maintenance** of the wooden buildings are quite complex. Most of the studies show that wooden buildings need more maintenance. For green roofs, there is a need for more care of plants, such as watering and cleaning. In the case of wooden buildings, the maintenance costs are similar for wooden frame and concrete frame [6]. In Sweden, there are **new standards** for climate declaration A1-5 (are needed for building in 2022) and B2,4,6 and C and limit values for A1-5 (are needed for buildings in 2027). These are based on the Swedish national boards of Housing [7].

5 Conclusion and outlook

The results indicate that wooden building structures are not enough for a complete biogenic building to move towards a renewable, fossil-free future. The biogenic carbon stored in wooden materials is relatively high (84%). However, the biogenic carbon stored in wooden buildings overall is not enough (60%) to outweigh GHG emissions from other materials built in the building. To improve the environmental profile of the analysed wooden building, more biobased insulation materials need to be used, such as wooden fibre insulation. For a break-even of biogenic carbon stored and GHG emissions, only 10% of the insulation needs to be wooden based. This can be reached for example in wall or roof insulation.

Furthermore, the green roofs do add more biogenic carbon to the building than conventional roofs, while seen over the whole building these benefits are negligible. The biogenic carbon stored in green roofs is relatively high (60%) compared to conventional roofs (0-19%). However, the amount of carbon stored in green roof is relatively low compared to the complete building (only 5%). To improve the environmental profile of the analysed green roof, more biobased plastics in the waterproof layer and textile layer need to be used.

In the future, the building industry needs to shift their focus from green roof to biobased insulation. For an environmental return of investment (break-even analysis of biogenic carbon), the buildings need to focus on other materials, such as insulation. Biogenic carbon can be used as a strategy to reach Net Zero Emission Buildings, and the GHG emissions from energy use during use phase (B6) need to be as large as the production phase (A1-3).

Acknowledgement: This work was granted by the Swedish Energy Agency (No 46829-1).

References

1. Nordic Council of Ministers (2017). *Nordic Bioeconomy: 25 cases for sustainable change.* 2016:782, ISBN 978-92-893-4776-1. http://dx.doi.org/10.6027/ANP2016-782.
2. J. Schade, J. Mukkavaara, B. Brunklaus, Greenhouse gas emissions and sustainability of green roofs and stormwater systems on a district level – comparisons with a life cycle perspective, *10th Int. Conf on LCM 2021*, 5-7th of Sept 2021, Stuttgart, Germany (2021).
3. M. Wall, Energy-efficient terrace houses in Sweden: Simulations and measurements, *Energy and Buildings*, **38** (6), 627-634 (2006).
4. S. Attia (2018). Materials and Environmental Impact Assessment. In: *Net Zero Energy Buildings*. Elsevier, 155-187. https://doi.org/10.1016/B978-0-12-812461-1.00006-X.
5. Sweden Energy (2021). *Emission factors for district heating in Sweden*. (www.energiforetagen.se, accessed 2021-10-24)
6. E. Levander, Y. Sardén (2008). Maintenance and operating costs in offsite timber framed housing. (www.ltu.se, accessed 2021-10-24)
7. Boverket (2020). *Utveckling av regler om klimatdeklaration av byggnader*. 2020:13. Klimatdeklaration av byggnader. Förslag på metod och regler. 2018:23. Sweden.