https://doi.org/10.17221/65/2023-JFS

Forest as a source of renewable material to reduce the environmental impact of buildings

*Hana Svobodová, Petra Hlaváčková**

Department of Forest and Wood Product Economics and Policy, Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic

**Corresponding author: petra.hlavackova@mendelu.cz*

Citation: Svobodová H., Hlaváčková P. (2023): Forest as a source of renewable material to reduce the environmental impact of buildings. J. For. Sci., 69: 451–462.

Abstract: The construction sector has a high environmental impact throughout the entire life cycle of buildings. One way to reduce the impact is to use building materials with the lowest possible environmental impact – such as wood. The use of wood-based building materials can improve the overall environmental balance of buildings. Compared to other materials, wood probably has the best environmental performance. These findings are particularly significant in the context of the environmental and legislative situation in Europe and the Czech Republic and may be one of the reasons for the increasing number of new wood-based buildings. The main reason for the research is to highlight the potential of wood as an ecological renewable material with multiple applications in all sectors of the national economy, especially in the construction industry. This paper aims to deepen the knowledge of the environmental specifications of building materials, especially wood, highlight its benefits and verify that building with natural and eco-friendly materials is less costly with lower environmental impacts. To illustrate the environmental impact of the construction industry, a case study comparing house variants was conducted to find the most suitable combinations of materials in terms of economic, environmental, and social aspects. It was found that from a sustainable development perspective, building with green materials generally means lower environmental impacts measured e.g. by global warming potential and embodied energy. This is particularly evident in the case of wood, which is not only a renewable material with advantageous thermo-technical and construction properties despite its low weight, but also stores carbon as it grows. The findings show that wood in the structure can reduce the cumulative environmental impact of the whole structure.

Keywords: circular economy; eco-design; forestry; life cycle assessment; timber supply chain; wood-based construction; wood utilisation

Wood, as one of the main products of forestry, is a renewable raw material with large application in all sectors of the national economy [as evidenced, for example, by Saidur et al. (2011), Kromoser et al. (2022), or Zastempowski (2023)] and whose use helps to protect the environment and meet sustainable development goals. The consumption of wood is supported by various international and European documents that are binding for the Czech Republic, such as the Green Deal (European Commission 2019) and the New EU Forest Strategy for 2030 (European Commission 2021) and their successors. Wood is an energy-efficient, low-carbon building material that can make a significant contribution to achieving European climate policy objectives in urban environments if managed carefully (Sikkema et al. 2023).

The construction industry, along with its associated materials industry, consumes a huge volume

Supported by the European Union's Horizon 2020 research and innovation programme under grant agreement No. 952314.

https://doi.org/10.17221/65/2023-JFS

of natural resources – in the 1990s it was over 40% of consumption (Rees 2010), a figure that has subsequently fallen to around 32% (Yeheyis et al. 2013). Thus, it is a very significant contributor to the current unsustainable development of the world economy (Spence, Mulligan 1995). The construction industry is also responsible for a quarter of the solid waste amount generated worldwide (Yeheyis et al. 2013), but in developing countries, it can reach even higher numbers and there are additional problems with illegal disposal of construction waste (incineration, illegal dumpsites) (Mahayuddin et al. 2008; Nagapan et al. 2013; and others).

Timber structures offer great potential in promoting a more sustainable approach in the construction industry. From the growth of the tree, through the stage where the wood is used, to the dismantling and recycling of the wood as a building material, wood represents a completely closed material cycle (if the associated emissions are neglected). In addition, wood partially stores CO_2 during the tree's growth phase. Since half of the weight of wood is carbon, one kilogram of carbon corresponds to 3.6 kg of CO_2, i.e. one kilogram of wood binds approximately 1.8 kg of CO_2. However, despite its renewable nature, wood is a limited resource and currently a significant amount of processed raw material that ends up in secondary streams is used as fuel (Kromoser et al. 2022). Compared to other building materials used for the construction of frame buildings, wood probably has the best environmental properties and sustainability, especially in terms of life cycle assessment (Woodard, Milner 2016).

According to the Intergovernmental Panel on Climate Change (IPCC) report, global climate change is a reality and most of its impacts are the result of human activity and anthropogenic greenhouse gas (GHG) emissions (IPCC 2007). These emissions, which are one of the main drivers leading to climate change, coupled with unpredictable extreme weather events, can cause negative impacts on food supply, electricity, transport, industry, buildings and land use (IPCC 2014).

The construction industry is currently affected by various factors. Despite the existence of doubts and opposing opinions regarding the causes of global warming (perceptions of global warming and its causes have been dealt with e.g. by Verheggen et al. 2014, Abeles et al. 2019), it is a fact that governments exert legislative pressure to reduce greenhouse gas emissions and energy consumption in many areas of human activity. Considering that buildings account for up to 40% of global energy consumption and greenhouse gas emissions (Morel et al. 2001; UNEP 2009; and others), research on minimising energy consumption and carbon emissions during their life cycle has received increasing attention in recent years. In this context, the EU introduced the concept of nZEB – nearly zero energy building and at the same time, other frameworks that promote the energy efficiency of buildings, such as the passive house, have gained wide recognition. A number of authors dealt with the evaluation of these concepts (e.g. Tsikaloudaki et al. 2022). In 2007 and in 2014, the European Council adopted targets to reduce emissions by 20% by 2020 and by at least 40% by 2030. For 2020 and 2030, these emission reduction targets were supplemented by targets for the share of renewable energy in total energy consumption (20% by 2020 and 32% by 2030) and for energy efficiency improvements (20% for 2020 and 32.5% for 2030). By 2030, emissions should be reduced to at least 55% of 1990 levels (an intermediate step known as Fit for 55). The emission reduction targets for 2020 and 2030 are legally binding and provide clear guidance for policymakers and stakeholders (Oberthür 2010). The requirements for the use of environmentally friendly materials are set out in the Regulation of the European Parliament and the EU Council No. 305/2011. These requirements are an incentive to evaluate products in terms of environmental impact.

Two consecutive cost shocks have recently had a significant impact on the European construction industry: in 2021, during the economic recovery phase after the COVID-19 pandemic, there was a significant increase in costs, which was mainly caused by an unexpectedly fast economic recovery. The second massive cost jump in 12 months followed the war in Ukraine. Due to the very energy-intensive production technology of many building materials, there has been a significant increase in prices (Klien 2023).

In the area of environmental protection in the context of the construction industry, new sources of energy, or energy savings during the use of the building, have so far been more researched, see e.g. Harris (2005). In the Czech Republic, energy management and energy savings during the use of buildings are dealt with by laws (406/2000 Coll., Building Act) and their implementing regulations (264/2020 Coll., 268/2009 Coll.). In practice, therefore, the energy need for the operation of buildings is currently the most evaluated, the neglected

https://doi.org/10.17221/65/2023-JFS

energy input when calculating the energy balance is the bound energy of materials [*PEI* (MJ)] indicating the total consumption of natural energy sources during the life cycle of the product. By including bound energies in a complex design, it is possible to assess the energy efficiency of structural components and to determine the influence and importance of individual parts on the overall energy demand. Considering the sustainable development perspective, green building materials with non-toxic, natural and organic compounds have the potential to reduce the overall impact on the environment and human health (Khoshnava et al 2020).

One possible alternative path is a construction approach which seeks to minimise the environmental impact of the design, construction, operation, and disposal of houses. This includes a wide range of building systems and materials, all of which share an emphasis on sustainability. For example, the energy rating considers not only the energy used in the operation, but also the energy used for the production and disposal of building materials. A number of analyses and research studies has been conducted in the past examining the relationship between construction and sustainability from a life cycle perspective (e.g. Spence, Mulligan 1995; Sev 2008; Ortiz et al. 2009; Hwang et al. 2012; Tushar et al. 2021). For example, it has been demonstrated to what extent the use of local materials can improve the overall balance of a building – e.g. according to Morel et al. (2001), the amount of energy consumed in construction has been reduced by up to 215% and the impact of transport by 453% by means of using local materials (such as stone, clay, wood). Also, the potential of using circular economy principles has been explored, which, among other things, keeps materials and resources in a closed loop, minimises waste and allows for a reduction in the use of primary non-renewable resources (Adams et al. 2017; Ogunmakinde et al. 2022).

In recent years, particularly in Europe and North America, increased attention has also been paid to multi-story wood buildings (MSWBs), which provide space for renewability, recyclability, and carbon storage that multi-story buildings made of other load-bearing materials do not offer (Hurmekoski et al. 2018). Wood-based buildings show overall better environmental performance, as shown, for instance, in a comparison of concrete and wood-based building technologies in a European framework (Guardigli 2014). However, there is also interest in wood-based buildings in other countries – for example, research has been conducted in China comparing a high-rise building made of CLT (cross laminated timber) with a concrete building located in a cold and very cold climate region of the country. The results showed that the use of CLT as a replacement for conventional carbon-intensive material (concrete) would reduce energy consumption by more than 30% and reduce CO_2 emissions by more than 40% in the cradle-to-grave LCA study (Liu et al. 2016).

The aim of the paper is to analyse the use of wood and its potential as a renewable and sustainable material in the construction industry. To illustrate the environmental impact of the construction industry, a case study comparing different variants of one type of new house construction project was compiled. In this way, different compositions of timber-based construction could be compared with the outcome of finding the most suitable combination of the specified parameters in terms of sustainable construction, i.e. from an ecological, economic and social perspective. For the compositions of the structures, materials were selected from conventional building materials (CBMs) (e.g. polystyrene, mineral wool, asphalt strips) and from available ecological materials (wood, wood-fibre thermal insulation etc.). The compositions were assembled to have a comparable heat transfer coefficient and to comply with the basic design principles and the standard ČSN 73 0540-2/2011. This case study documents wood as a renewable resource that is an environmentally friendly material suitable for use in construction.

MATERIAL AND METHODS

The research was carried out according to a procedure consisting of the following steps: (*i*) development of the main hypothesis and sub-hypotheses, (*ii*) operationalisation of the established hypotheses into a research tool (calculation schemes for the evaluation of individual proposed structures and buildings), (*iii*) data collection, (*iv*) data evaluation, and (*v*) overall evaluation.

Hypotheses. The main hypothesis and sub-hypotheses were formulated. Construction using wood and wood-based materials is beneficial to the construction industry from a sustainable development perspective. The sub-hypotheses are the claims that wood-based construction has lower environmental impacts and is less costly.

https://doi.org/10.17221/65/2023-JFS

Data collection and evaluation. Empirical and logical methods (such as analysis and synthesis, comparison, deduction, generalisation) of scientific work and creative solutions were used to meet the research objectives. The collection and classification of scientific and technical information on the current state of the problem is based on the principle of analysis of available scientific publications with subsequent synthesis into a comprehensive overview. First, the current situation in the construction industry in Europe and especially in the Czech Republic was analysed, with a focus on the field of wood-based buildings. For this purpose, the outputs of the EUROCONSTRUCT research group which deals with research and analysis of the construction industry, data provided by the Czech Statistical Office, and scientific articles on this topic were examined. The current requirements for buildings and their energy ratings, and the requirements for materials and their properties were summarised. The area of trends in EU climate policy (such as various Regulations of the European Parliament and of the Council of the EU, European standards, Green Deal) affecting the construction sector was examined. Attention was also given to environmental protection, environmental impacts, and waste reduction in the context of the construction industry.

The necessary information to assess and compare the technical, environmental and economic aspects of the materials proposed for the construction of the model building was obtained from available literature sources and tables, professional publications, databases (e.g. Envimat 2013; Baubook 2023) and documents, such as EPDs (Environmental Product Declarations) from specific manufacturers (which are generally available via Baubook). The selection of values considered their comparability (methodology, legislation) and timeliness.

The constructed model design solutions of the type building were assessed from the structural (structural and thermal technical properties – thermal resistance and heat transfer coefficient of the structure), environmental (determination of environmental impacts in the selected impact categories – global warming, acidification of environment and non-renewable primary energy) and economic [model calculations of material costs based on the indicative price per m^3 of built-up area provided by RTS, a.s. (2023)] point of view and the system boundaries were determined. The results were further processed and compared in absolute and percentage terms.

As far as environmental performance is concerned, values from the production phase of the products, i.e. cradle-to-gate [according to EN 15978 (2011)] – from the extraction of raw materials, through transport to the plant to the actual production – were used. This method is often used in practice. The environmental impact categories to be examined were selected. The output was then a set of impact category indicator results with specific values and clearly defined units. For a simplified comparison of the proposed designs, the identified impact category values were scored and subsequently compared.

Overall evaluation. The shape, building layout, and structural systems were designed to meet the legislative and technical requirements for buildings. The structural systems were used for the proposed building so that the external dimensions and therefore the built-up area were maintained. The structural compositions were designed to have a comparable heat transfer coefficient and to comply with the standard ČSN 73 0540-2/2011. Thus, the main structures of the gross building – the vertical load-bearing structures (external and internal walls), the horizontal load-bearing structures (ceilings), the roof structures, and the components of the structure, such as windows or tiles, were assessed.

The hypotheses are tested by comparing the assumptions with the data obtained. When hypotheses (assumptions) agree with data, they inductively support the truth of a logical construct or universal statement (and theory). If the data obtained contradict the stated hypotheses, either the construct (theory) was flawed, or there was an error in deductive hypothesis generation, or an error in data collection and evaluation (Ochrana 2009).

For the purposes of this case study, a new construction of a single-family house without a basement was chosen, with a simple rectangular floor plan on foundation passes with a foundation slab, with a gable roof. Variants of the structural design with uniform external dimensions and thus equal built-up area were developed. The external plan dimensions are identical for all variants – 12.5 m × 8 m. The house meets the technical requirements for buildings specified by Decree No. 268/2009 Coll. and the required values of the heat transfer coefficient given by the standard ČSN 73 0540-2.

The upper structure is then designed in three main types (see Table 1 for further details):

(*i*) Timber-frame construction, 'green' variant: timber-framed post-and-beam construction with

https://doi.org/10.17221/65/2023-JFS

Table 1. Details on individual variants

Building features	Variant A (frame construction – green)	Variant B (frame construction – conventional)	Variant C (CLT)
Building shape and size	rectangular floor plan 12.5 m × 8 m, gable roof, residential attic, no basement	rectangular floor plan 12.5 m × 8 m, gable roof, residential attic, no basement	rectangular floor plan 12.5 m × 8 m, gable roof, residential attic, no basement
Overall dimensions (total floor area)	floor area 1st floor 79.9 m^2, attic 78.2 m^2 – total 158.1 m^2	floor area 1st floor 79.9 m^2, attic 78.2 m^2 – total 158.1 m^2	floor area 1st floor 82.7 m^2, attic 79.9 m^2 – total 162.6 m^2
Structural system and foundations	frame wooden construction on foundation belts and slab, gable roof with wooden truss	frame wooden construction on foundation belts and slab, gable roof with wooden truss	wooden construction from the CLT board system on foundation belts and slab, gable roof with wooden truss
Frame (beams, columns, slabs)	walls made of wooden columns with a cross-section of 160/60 mm (KVH), axial distance 625 mm	walls made of wooden columns with a cross-section of 160/60 mm (KVH), axial distance 625 mm	load-bearing walls based on massive wooden panels – CLT, CLT panel thickness 84 mm
Non-load-bearing elements	non-load-bearing walls made of wooden posts measuring 60 mm × 100 mm	non-load-bearing walls made of wooden posts measuring 60 mm × 100 mm	non-load-bearing walls based on massive wooden panels – CLT
External walls	walls made of wooden posts with a cross-section of 160/60 mm (KVH), axial distance 625 mm	walls made of wooden posts with a cross-section of 160/60 mm (KVH), axial distance 625 mm	load-bearing walls based on massive wooden panels – CLT, CLT panel thickness 84 mm
Windows	wooden windows with triple glazing	PVC windows with triple glazing	wooden windows with triple glazing
Roof	roof pitch 40°, carpentry roof, roof covering – concrete tiles, skylights	roof pitch 40°, carpentry roof, roof covering – concrete tiles, skylights	roof pitch 40°, carpentry roof, roof covering – concrete tiles, skylights
Internal walls	load-bearing walls made of wooden posts (cross section 60 mm × 160 mm); non-load-bearing walls made of wooden posts with a cross section 60 mm × 100 mm	load-bearing walls made of wooden posts (cross section 60 mm × 160 mm); non-load-bearing walls made of wooden posts with a cross section 60 mm × 100 mm	load-bearing walls based on massive wooden panels – CLT, CLT panel thickness 84 mm
Flooring	1st floor on RC slab – thermal insulation, cement screed (with heating element), levelling screed and flooring layer; 2nd floor on frame construction – thermal and noise insulation, distribution layer, flooring layer	1st floor on RC slab – thermal insulation, cement screed (with heating element), levelling screed and flooring layer; 2nd floor on frame construction – thermal and noise insulation, distribution layer, flooring layer	1st floor on RC slab – thermal insulation, cement screed (with heating element), levelling screed and flooring layer; 2nd floor on CLT construction – thermal and noise insulation, distribution layer, flooring layer
Floors	floor construction with KVH joists 60/240 mm, axial distance 625 mm	floor construction with KVH joists 60/240 mm, axial distance 625 mm	construction with a load bearing CLT panel

CLT – cross laminated timber; KVH – solid construction timber (Konstruktionsvollholz); RC – reinforced concrete
Source: Own processing

https://doi.org/10.17221/65/2023-JFS

blown wood fibre insulation and facade fibreboard insulation; floor structure with load-bearing timber beams with blown wood fibre insulation; roof structure insulated with blown fibre insulation and fibreboard insulation for the roofs.

(*ii*) Timber-frame construction, conventional variant: timber-framed post-and-beam construction with mineral wool insulation; floor structure with supporting wooden beams with mineral wool insulation; roof structure with mineral wool insulation.

(*iii*) CLT-based construction: load bearing CLT panels with wood fibre insulation, with a wooden facade with a wood fibre insulation facade board; floor structure: composition with supporting wooden beams; roof structure insulated with blown wood fibre insulation and with insulating wood fibre board for roofs.

The characteristic design service life of the building according to AN ČSN EN 1990 is 80 years. For the purpose of calculating the renewal cycles of individual elements and components of the building, the values of the expected service life from the Valuation Decree No. 441/2013 Coll. – Decree on the implementation of the Act on the Valuation of Property were used. Thus, for example, one replacement of roofing, one replacement of ceramic tiles in the interior, etc. was determined.

The thermal resistance and heat transfer coefficient of the structure were determined according to the applicable standards. The results were compared with the requirements of the current ČSN 73 0540-2:2011 and with each other. The coefficients used in the work were obtained from available data of manufacturers, standards, data from the TZB-info internet portal, Baubook database, etc.

Due to the increasingly stringent legislative requirements for buildings, the most restrictive requirement was chosen – the recommended value for passive houses $U_{pas,20}$.

The next range of construction properties evaluated were selected environmental properties: (*i*) *PEI* – primary energy input, (*ii*) *GWP* – global warming potential, (*iii*) *AP* – acidification potential.

The environmental values of materials are most often reported in EPDs and available databases in the production phase range [modules A1–A3 according to EN 15978 (2011)]. These values have also been used for the purpose of this case study.

RESULTS

Thermal-technical properties. The appropriate assembly of the compositions for the individual building variants resulted in comparable values of the heat transfer coefficient (U) and the resistance of the structures to heat transfer (R_T; see Table 2). At the same time, the resulting values met the recommended values for passive values proposed by ČSN 73 0540-4 and ČSN EN ISO 6946 (Table 3).

Table 2. Summary of resulting heat transfer coefficients and thermal resistances of envelope structures

Construction type	U (W·m^{-2}·K^{-1})			R_T (m^2·K·W^{-1})		
	variant A	variant B	variant C	variant A	variant B	variant C
Floor on the ground	0.19	0.18	0.19	5.35	5.64	5.35
Perimeter wall	0.16	0.14	0.15	6.41	7.00	6.74
Roof construction	0.15	0.14	0.15	6.76	7.20	6.76

Variant A – timber-frame construction, 'green' variant; variant B – timber-frame construction, conventional variant; variant C – CLT-based construction; R_T – thermal resistance; U – heat transfer coefficient

Table 3. Overview of required values of heat transfer coefficient according to ČSN 73 0540-4 and ČSN EN ISO 6946

Construction type	Required value $U_{N,20}$ (W·m^{-2}·K^{-1})	Recommended value $U_{rec,20}$ (W·m^{-2}·K^{-1})	Demand value for passive buildings $U_{pas,20}$ (W·m^{-2}·K^{-1})
Floor on the ground	0.45	0.30	0.22–0.15
Perimeter wall – lightweight	0.30	0.20	0.18–0.12
Roof up to 45°	0.24	0.16	0.15–0.10

$U_{N,20}$ – required value of the heat transfer coefficient for buildings with a predominant design internal temperature between 18 °C and 22 °C inclusive; $U_{rec,20}$ – recommended value of the heat transfer coefficient for buildings with a predominant design internal temperature between 18 °C and 22 °C inclusive; $U_{pas,20}$ – recommended value of the heat transfer coefficient for passive buildings with a predominant design internal temperature between 18 °C and 22 °C inclusive

https://doi.org/10.17221/65/2023-JFS

Table 4. Comparison of environmental impacts of individual construction alternatives – Quantified for the whole construction

Construction type	PEI_C (MJ)	GWP_C (kg CO_2 eq.)	AP_C (g SO_2 eq.)
Variant A	583 811.07	2 314.20	151 460.65
Variant B	776 606.03	23 684.06	214 008.41
Variant C	672 942.57	–3 855.48	173 176.37

Variant A – timber-frame construction, 'green' variant; variant B – timber-frame construction, conventional variant; variant C – CLT-based construction; AP_C – acidification potential of the construction; eq. – equivalent; GWP_C – global warming potential of the construction; PEI_C – primary energy input for the construction

Environmental properties. The predicted replacements of structures and elements have been included in the summary environmental performance of the individual options as shown in Table 1. The comparison is shown in Table 4. A graphical comparison of the environmental impacts of the individual options is shown in Figure 1.

By quantifying the *PEI*, *GWP*, and *AP* values of individual structures, it was found that the lowest environmental impact is for structures made of natural and more environmentally friendly materials – variants A and C. Variant C even achieved a negative balance of global warming potential.

Since the individual variables cannot be added up and thus the constructions cannot be compared to each other, the individual constructions were compared using a score (Table 5).

For the basic economic comparison of the individual variants, the indicative prices per m^3 of built-up space provided by RTS, a.s. (RTS 2023) were used. The development of indicative prices for the period 2013–2023 per m^3 of built-up space is shown in Figure 2. The year-on-year change in the price per m^3 of built-up space is shown in Figure 3.

According to the data on the average price per m^3 of built-up space, since 2017 the average price of buildings with a wood-based structure

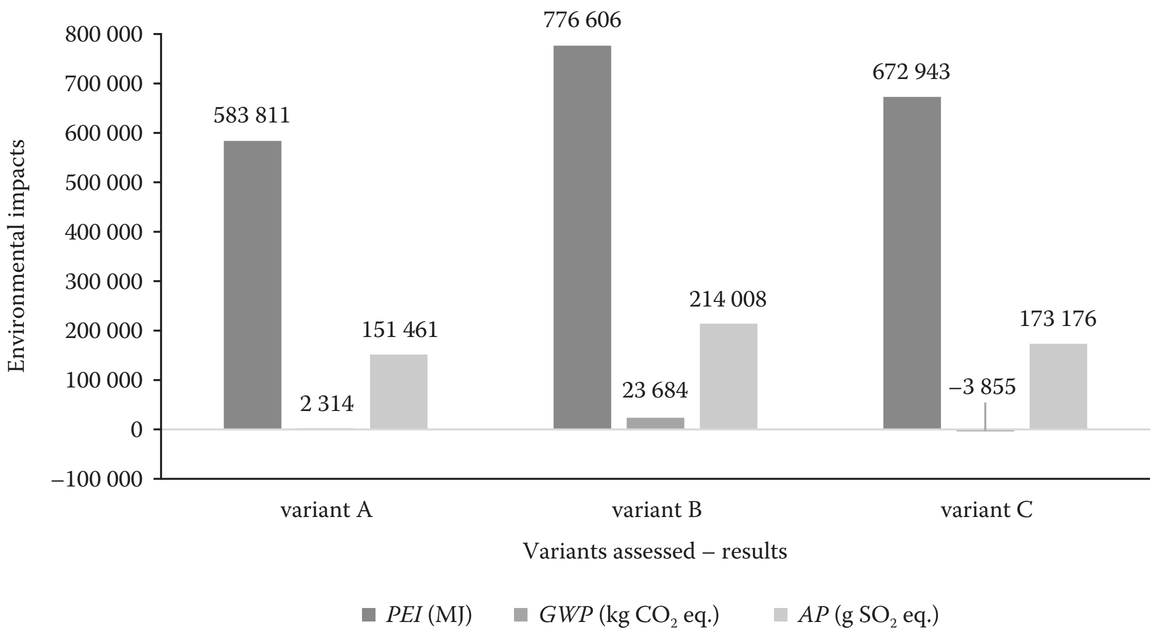

Figure 1. Graphical representation of environmental impacts of individual construction variants – Quantified for the whole construction

Variant A – timber-frame construction, 'green' variant; variant B – timber-frame construction, conventional variant; variant C – CLT-based construction; *AP* – acidification potential; eq. – equivalent; *GWP* – global warming potential; *PEI* – primary energy input

https://doi.org/10.17221/65/2023-JFS

Table 5. Scores and comparisons of individual buildings based on environmental values

Assessed characteristics	Variant A	Score	Variant B	Score	Variant C	Score
PEI_{BA} (MJ·m^{-3})	895.42	1	1 191.11	3	1 020.54	2
GWP (kg CO_2 eq. ·m^{-3})	3.55	2	36.33	3	–6.42	1
AP (g SO_2 eq. ·m^{-3})	232.30	1	328.23	3	262.73	2
PEI_m (MJ·kg^{-1})	4.25	1	6.33	3	4.49	2
GWP (kg CO_2 eq. ·kg^{-1})	0.02	2	0.19	3	–0.03	1
AP (g SO_2 eq. ·kg^{-1})	1.10	1	1.74	3	1.15	2
Total	–	8	–	18	–	10

Variant A – timber-frame construction, 'green' variant; variant B – timber-frame construction, conventional variant; variant C – CLT-based construction; AP – acidification potential; eq. – equivalent; GWP – global warming potential; PEI_m – primary energy input per 1 kg of construction; PEI_{BA} – primary energy input per 1 m^3 of built-up area

is lower than the average price of masonry buildings (RTS, a.s. 2023).

To obtain a more accurate picture of the material cost of the rough construction of each structure, the material cost of each structure was quantified according to RTS, a.s. data. The resulting prices were determined for the material used in the scope of the rough construction, excluding VAT and excluding losses due to e.g. cutting of materials. In terms of materials the costliest construction is variant C (EUR 108 480),

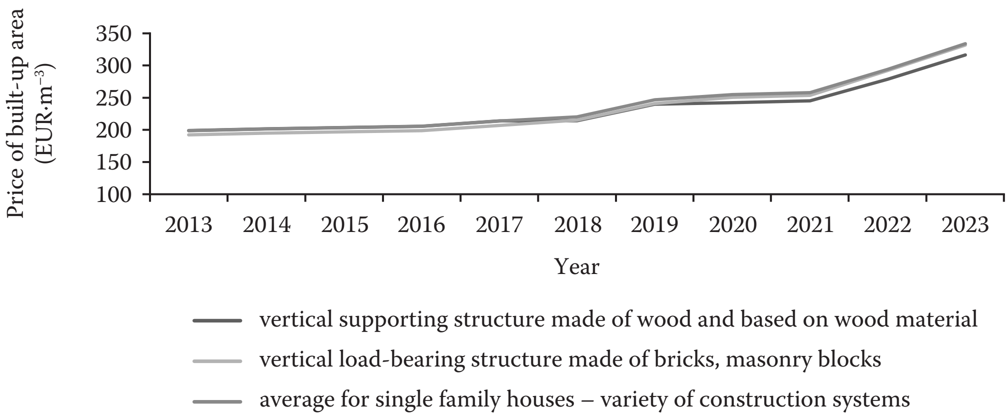

Figure 2. Indicative price per m^3 of built-up area of a single-dwelling house trend from 2013 to 2023

Source: Own processing according to RTS 2023

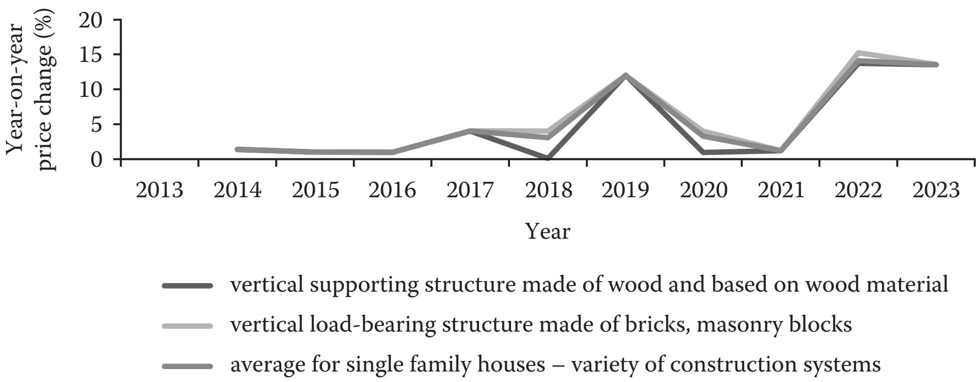

Figure 3. Annual price change per m^3 of built-up area of a single-dwelling house from 2013 to 2023

Source: Own processing according to RTS 2023

https://doi.org/10.17221/65/2023-JFS

followed by variant A (EUR 99 327) and variant B (EUR 76 909). This finding contradicts the claim of the sub-hypothesis that construction with natural and ecological materials is less costly. The hypothesis is hereby rejected.

DISCUSSION

The construction industry is a major contributor to global energy consumption and carbon dioxide emissions throughout the life cycle of buildings (Gan et al. 2020). Therefore, the use of renewable materials or materials that are more environmentally friendly and meet sustainability standards is now gradually gaining ground in the construction sector. The main motivation for this effort to change the established model of the construction industry has been the realisation that the Earth's natural resources are diminishing (Barnosky et al. 2011; UNDP 2013) and the ecological footprint (human demands vs. the Earth's ability to renew itself) is increasing (Carter 2007). Some of the options for minimising the impact of construction are eco-design or green building technologies. Combined with eco-design principles, green building technologies and materials such as wood have the potential to contribute enormously to the required reduction in energy and material consumption (Wang et al. 2014), even on a global scale (Rees 2010). Green building standards and forest certification have been developed to reduce the environmental impact caused by the construction sector (Espinoza et al. 2012). The use of wood in construction can in turn help mitigate climate change – through additional carbon storage in buildings and by replacing steel, concrete and other fossil fuel-intensive materials (e.g. Matsumoto et al. 2016; Hafner, Rüter 2017; Hildebrandt et al. 2017; Piccardo, Gustavsson 2021). The forestry sector can have a significant impact on climate change by increasing carbon stocks (e.g. Canadell, Raupach 2008; Grassi et al. 2021). This corresponds to the findings from the case study, where buildings with a higher use of wood and wood-based materials have a better carbon balance and a lower potential for acidification of the environment (green version of a frame building, CLT building).

Envimat was created because there was no similar database in the Czech Republic (Hodková et al. 2012). Unfortunately, since its creation in 2010, only a few updates have been made, the last one in 2013. Most of the data still comes from the Swiss Ecoinvent, so the data is not sufficiently up-to-date and relevant for the Czech environment. It would be advisable to renew the database and update the data to allow builders to make decisions based on the environmental performance of materials as well. It is highly plausible that this aspect will become more important in the future. Current policy and legislation [such as Regulations (EU) 2018/410, 2018/841, 2018/842, and 2018/844 of the European Parliament and of the Council] indicate this scenario. This trend is also an opportunity for more efficient use of Czech wood as a building material – structural timber, raw material to the production of complementary materials (thermal insulation, etc.). It could be a way to valorise lower quality timber such as pulpwood or calamity wood.

Forestry sector is in the cyclical sector that is strongly influenced by cyclical calamities. These calamities also understandably affect timber prices – largescale calamities drive down wood prices due to large volumes of harvested timber (Toth et al. 2020). This cyclical phenomenon in the logging industry is significant across the whole of central Europe and the large timber volumes are accelerated by higher temperatures, drought, and by negative weather and climatic events (Šimůnek et al. 2020; Hlásny et al. 2021).

As mentioned above, timber from salvage logging could also be better valorised in this way, so that builders and the wood industry can profit from calamities. Lower quality timber can be used as a resource for a variety of construction and insulation materials. This topic is worthy of more research, considering the insufficient capacity to process calamity wood in the Czech Republic (Toth et al. 2020). The increased use of wood products in the European Union may contribute to a shift towards the production of more emission-efficient building materials, and the market share of wood-based construction materials (such as LVL – laminated veneer lumber, CLT, OSB – oriented strand board and others) is already steadily increasing (Hildebrandt et al. 2017).

Further research is needed to verify the generalisability of the conclusions and design guidelines. However, this research is an important step in promoting the use of green building materials and elements and in promoting the use of wood and wood-based materials in construction, also in the context of the expected increasing pressure

https://doi.org/10.17221/65/2023-JFS

and demand for the use of renewable materials in construction.

Assessing buildings in the context of their lifespan is another topic. The lifespan and durability of timber-based buildings are often questioned by builders and investors. Wood-based buildings are often considered to be less durable than conventional constructions (such as masonry or concrete buildings), even though, with the application of proper design and construction principles, wooden buildings can last for centuries, as evidenced by many surviving buildings around the world [for example Nanchan Temple in China which was built 1 200 years ago (Jing, Nishizawa 2022), Scandinavian stave churches from 12th century (Szilágyi, Sand-Eriksen 2021)].

CONCLUSION

The aim of the case study was to assess natural and ecological materials, especially wood, in terms of their utility and functional properties, environmental impacts and economic benefits for construction companies and builders. The study verified the hypothesis that building with natural and eco-friendly materials is beneficial for the construction industry in terms of sustainable development. The sub-objectives were to deepen the knowledge of energy and environmental specifications of building materials and to provide a basis for decision-making in the selection of materials in the design of new buildings and the rehabilitation of existing buildings. Further research is needed to verify the generalisability of the conclusions and design guidelines. However, this research is an important step in promoting the use of green building materials and elements.

The comparison of variants in the case study showed that the most environmentally friendly variant is a timber frame building with a wooden facade and thermal insulation based on wood fibres, followed by a building made of CLT panels and in the third place is a standard timber frame building with thermal insulation based on mineral wool. The structures that represent a major part of the buildings (such as foundation structures, perimeter walls) and the materials contained in the structures in the highest proportion (i.e. concrete, masonry blocks, insulation materials) have the greatest influence on the final values of the individual buildings. From this, it can be concluded that replacing certain structures or materials with more environmentally friendly options would in many cases improve the overall balance of the environmental impacts of the building. The findings support the sub-hypothesis that building with natural and ecological materials has lower environmental impacts and is thus not rejected.

These conclusions, together with the current situation in the construction industry and in the impacts of human activity in general, suggest that the assessment of buildings in terms of their energy and environmental performance may become increasingly important in the future.

The use of local materials with low environmental impact can be recommended to builders in general when choosing building materials.

The material costs in the scope of the rough construction were calculated according to the data of RTS, a.s. The resulting prices are determined for the material used in the scope of the rough construction, without VAT and without losses caused e.g. by cutting through materials. The CLT-based variant is the costliest construction, followed by the green frame construction variant 1 and the conventional timber frame construction variant. This finding contradicts the assertion of the sub-hypothesis that building with natural and green materials is less costly. This hypothesis is hereby rejected.

These findings, in the context of the current situation in the construction industry and the impacts of human activity in general and the outlook, suggest that the assessment of buildings in terms of their energy and environmental performance will become increasingly important. The article is beneficial for the construction sector as well as for the forestry sector. From the forestry perspective, the content of the article and its results can provide further arguments and a basis for the development of forestry policy application documents in the field of promoting the use and consumption of wood as a renewable and sustainable material.

REFERENCES

Abeles A.T., Howe L.C., Krosnick J.A., Macinnis B. (2019): Perception of public opinion on global warming and the role of opinion deviance. Journal of Environmental Psychology, 63: 118–129.

Adams K.T., Osmani M., Thorpe T., Thornback J. (2017): Circular economy in construction: Current awareness, chal-

https://doi.org/10.17221/65/2023-JFS

lenges and enablers. Proceedings of the Institution of Civil Engineers – Waste and Resource Management, 170: 15–24.

Barnosky A.D., Hadly E.A., Bascompte J., Berlow E.L., Brown J.H., Fortelius M., Getz W.M., Harte J., Hastings A., Marquet P.A., Martinez N.D., Mooers A., Roopnarine P., Vermeij G., Williams J.W., Gillespie R., Kitzes J., Marshall C., Matzke N., Mindell D.P., Revilla E., Smith A.B (2011): Approaching a state shift in Earth's biosphere. Nature, 486: 52–58.

Baubook (2023): Deklaration Zentrale. Vienna, Baubook GmbH. Available at: https://www.baubook.at/zentrale/ (in German).

Canadell J.G., Raupach M.R. (2008): Managing forests for climate change mitigation. Science, 320: 1456–1457.

Carter N. (2007): The Politics of the Environment: Ideas, Activism, Policy. 2nd Ed. New York, Cambridge University Press: 410.

Centrum pasivního domu (2021): Přísnější požadavky na výstavbu nových budov od 1. ledna 2022. Stavebnictví, Informační centrum ČKAIT. Available at: https://www.casopisstavebnictvi.cz/clanky-prisnejsi-pozadavky-na-vystavbu-novych-budov-od-1.-ledna-2022.html (in Czech).

EN 15978 (2011): Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method. Brussels, European Committee for Standardization: 60.

Envimat (2013): První český katalog stavebních produktů a dopadů jejich výroby na životní prostředí. Praha, ČVUT v Praze. Available at: http://www.envimat.cz/ (in Czech).

Espinoza O., Buehlmann U., Smith B. (2012): Forest certification and green building standards: Overview and use in the U.S. hardwood industry. Journal of Cleaner Production, 33: 30–41.

European Commission (2019): The European Green Deal. COM(2019) 640 Final. Brussels, European Commission: 28.

European Commission (2021): New EU Forest Strategy for 2030. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2021) 572 Final. Brussels, European Commission: 30.

Gan V.J.L., Lo I.M.C., Ma J., Tse K.T., Cheng J.C.P., Chan C.M. (2020): Simulation optimisation towards energy efficient green buildings: Current status and future trends. Journal of Cleaner Production, 254: 120012.

Guardigli L. (2014): Comparing the environmental impact of reinforced concrete and wooden structures. In: Pacheco-Torgal F., Cabeza L.F., Labrincha J., de Magalhães A. (eds): Eco-efficient Construction and Building Materials. Cambridge, Elsevier: 407–433.

Hafner A., Rueter S. (2018): Method for assessing the national implications of environmental impacts from timber buildings – An exemplary study for residential buildings in Germany. Wood and Fiber Science, 50: 139–154.

Harris J. (2005): Environmental and Natural Resource Economics: A Contemporary Approach. 2nd Ed. Boston, Houghton Mifflin: 528.

Hildebrandt J., Hagemann N., Thrän D. (2017): The contribution of wood-based construction materials for leveraging a low carbon building sector in Europe. Sustainable Cities and Society, 34: 405–418.

Hlásny T., König L., Krokene P., Lindner M., Montagné-Huck C., Müller J., Qin H., Raffa K.F., Schelhaas M.J., Svoboda M., Viiri H., Seidl R. (2021): Bark beetle outbreaks in Europe: State of knowledge and ways forward for management. Current Forestry Reports, 7: 138–165.

Hodková J., Lupíšek A., Mančík Š., Vochoc L., Žďára T. (2012): National platform for LCA data on building elements in the context of the Czech Republic. International Journal of Sustainable Building Technology and Urban Development, 3: 277–284.

Hurmekoski E., Pykäläinen J., Hetemäki L. (2018): Long-term targets for green building: Explorative Delphi backcasting study on wood-frame multi-story construction in Finland. Journal of Cleaner Production, 172: 3644–3654.

Hwang B.G., Tan J.S. (2012): Green building project management: Obstacles and solutions for sustainable development. Sustainable Development, 20: 335–349.

IPCC (2007): Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press: 976. Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

Jing S., Nishizawa H. (2022): Experimental study on the structural behavior of the oldest timber frame in China. Buildings, 12: 1860.

Khoshnava S.M., Rostami R., Mohamad Zin R., Štreimikienė D., Mardani A., Ismail M. (2020): The role of green building materials in reducing environmental and human health impacts. International Journal of Environmental Research and Public Health, 17: 2589.

Klien M. (2023): A perfect storm for European construction? Vienna, EUROCONSTRUCT, WIFO – Austrian Institute of Economic Research. Available at: https://www.euroconstruct.org/news/2023_01_at/

Kromoser B., Reichenbach S., Hellmayr R., Myna R., Wimmer R. (2022): Circular economy in wood construction – Additive manufacturing of fully recyclable walls made from renewables: Proof of concept and preliminary data. Construction and Building Materials, 344: 128219.

Liu Y., Guo H., Sun Ch., Chang W.S. (2016): Assessing cross laminated timber (CLT) as an alternative material for mid-rise residential buildings in cold regions in China – A life-cycle assessment approach. Sustainability, 8: 1047.

https://doi.org/10.17221/65/2023-JFS

Mahayuddin S.A., Pereira J.J., Badaruzzaman W.H.W., Mokhtar M.B. (2008): Construction waste management in a developing country: Case study of Ipoh, Malaysia. WIT Transactions on Ecology and the Environment, 109: 481–489.

Matsumoto R., Kayo Ch., Kita S., Nakamura K., Lauk Ch., Funada R. (2022): Estimation of carbon stocks in wood products for private building companies. Scientific Reports, 12: 18112.

Morel J.C., Mesbah A., Oggero M., Walker P. (2001): Building houses with local materials: Means to drastically reduce the environmental impact of construction. Building and Environment, 36: 1119–1126.

Nagapan S., Rahman I.A., Asmi A., Adnan N.F. (2013): Study of site's construction waste in Batu Pahat, Johor. Procedia Engineering, 53: 99–103.

Oberthür S. (2010): The New Climate Policies of the European Union: Internal Legislation and Climate Diplomacy. No. 15. Brussels, Vubpress: 339.

Ochrana F. (2009): Metodologie vědy: Úvod do problému. 1st Ed. Praha, Karolinum: 156. (in Czech)

Ogunmakinde O.E., Egbelakin T., Sher W. (2022): Contributions of the circular economy to the UN sustainable development goals through sustainable construction. Resources, Conservation and Recycling, 178: 106023.

Ortiz O., Castells F., Sonnemann G. (2009): Sustainability in the construction industry: A review of recent developments based on LCA. Construction and Building Materials, 23: 28–39.

Piccardo C., Gustavsson L. (2021): Implications of different modelling choices in primary energy and carbon emission analysis of buildings. Energy and Buildings, 247: 111145.

Rees W.E. (2010): The built environment and the ecosphere: A global perspective. Building Research & Information, 27: 206–220.

RTS (2023): Cenová soustava RTS DATA. Brno, RTS. Available at: http://www.cenovasoustava.cz/ (in Czech).

Saidur R., Abdelaziz E.A., Demirbas A., Hossain M.S., Mekhilef S. (2011): A review on biomass as a fuel for boilers. Renewable and Sustainable Energy Reviews, 15: 2262–2289.

Sev A. (2009): How can the construction industry contribute to sustainable development? A conceptual framework. Sustainable Development, 17: 161–173.

Sikkema R., Styles D., Jonsson R., Tobin B., Byrne K.A. (2023): A market inventory of construction wood for residential building in Europe – In the light of the Green Deal and new circular economy ambitions. Sustainable Cities and Society, 90: 104370.

Spence R., Mulligan H. (1995): Sustainable development and the construction industry. Habitat International, 19: 279–292.

Szilágyi K., Sand-Eriksen A. (2021): Medieval Norwegian wooden (stave) churches: Built heritage and places of memory. Hungarian Archaeology, 10: 30–40.

Šimůnek V., Vacek Z., Vacek S. (2020): Solar cycles in salvage logging: National data from the Czech Republic confirm significant correlation. Forests, 11: 1–22.

Takano A., Hafner A., Linkosalmi L., Ott S., Hughes M., Winter S. (2015): Life cycle assessment of wood construction according to the normative standards. European Journal of Wood and Wood Products, 73: 299–312.

Toth D., Maitah M., Maitah K., Jarolínová V. (2020): The impacts of calamity logging on the development of spruce wood prices in Czech forestry. Forests, 11: 1–13.

Tushar Q., Bhuiyan M.A., Zhang G., Maqsood T. (2021): An integrated approach of BIM-enabled LCA and energy simulation: The optimized solution towards sustainable development. Journal of Cleaner Production, 289: 125622.

UNDP (2013): Human Development Report 2013. The Rise of the South: Human Progress in a Diverse World. New York, United Nations Development Programme. Available at: https://hdr.undp.org/system/files/documents/global-report-document/hdr2013encompletepdf.pdf

United Nations Environment Programme (2009): Buildings and Climate Change: Summary for Decision Makers. Available at: https://wedocs.unep.org/20.500.11822/32152

Verheggen B., Strengers B., Cook J., Van Dorland R., Vringer K., Peters J., Visser H., Meyer L. (2014): Scientists' views about attribution of global warming. Environmental Science & Technology, 48: 8963–8971.

Wang L., Toppinen A., Juslin H. (2014): Use of wood in green building: A study of expert perspectives from the UK. Journal of Cleaner Production, 65: 350–361.

Woodard A.C., Milner H.R. (2016): Sustainability of timber and wood in construction. In: Khatib J.M. (ed.): Sustainability of Construction Materials. Cambridge, Elsevier: 129–157.

Yeheyis M., Hewage K., Alam M.S., Eskicioglu C., Sadiq R. (2013): An overview of construction and demolition waste management in Canada: A lifecycle analysis approach to sustainability. Clean Technologies and Environmental Policy, 15: 81–91.

Zastempowski M. (2023): Analysis and modeling of innovation factors to replace fossil fuels with renewable energy sources – Evidence from European Union enterprises. Renewable and Sustainable Energy Reviews, 178: 113262.

Received: June 15, 2023
Accepted: August 18, 2023