The potential impacts of using bio-based building materials on human health and wellbeing.

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Abstract. When selecting building materials, health and wellbeing are aspects that are frequently neglected. It has been discovered that traditional materials are a source of hazardous emissions that have a negative impact on the health of individuals. On the other hand, Bio-based Building materials are increasingly being used instead of conventional materials as the construction sector aims to be more sustainable. However, these materials' potential impacts on human health and wellbeing are also a source of worry. As a result, the purpose of this study is to present a comprehensive review of pertinent scientific research, with a focus on comparative studies that shed light on the effects of using bio-based building materials. Considering both positive and negative health effects, with a focus on indoor environment quality, indoor contaminants, and psychological health and well-being. The results highlight the need for more study and provide insightful information about how using bio-based building materials affects individuals' health and well-being.

1 Introduction

Health is an essential factor to consider during the conception and construction phase of buildings. As construction materials are a key component, it should be selected after giving health and wellbeing effects further consideration. Given that most of our time is spent inside, maintaining a healthy indoor environment is necessary.

Thus, indoor environment quality (IEQ) depends on thermal, acoustic, visual, and indoor air quality (IAQ) [1,2] that affects directly human' health and wellbeing. Along with the effects of daily human activity on IEQ, building materials emissions [3], microbial proliferation [4], or hygrothermal performance have longer-lasting effects. The concern linked with building materials is the release of toxic compounds, which can cause a variety of respiratory health problems [5], especially when there is inadequate ventilation, yet providing IAQ is more than necessary. Recently in 2021, a set of guidelines for air quality levels has been published by the World Health Organization (WHO) [6]. Another guideline dated to 2010 about healthy buildings and health hazards includes "harmful building materials, radiation emitted by steel bars, high frequency electromagnetic waves, electromagnetic fields (EMF), temperature and humidity, hazardous particles, total volatile organic compounds (TVOCs) and formaldehyde" [7,8]. Likewise in the European Union, regulations related to volatile organic compounds (VOCs) emissions from materials were introduced such as the Solvent Emission Directive (SED) 1999/13/EC, the Products Directive (PD or DECO)2004/42/EC [9] and the Construction Products (CPD) [10].

According to some studies [11,12], conventional materials (CMs) are one of the main sources of volatile organic compounds (VOCs), especially in low-energy buildings, and Formaldehyde [13,14], that can lead to severe health issues such as sick buildings syndrome (SBS), allergies, immune system disorders and irritation to the eyes and nose. Negative emissions from materials are generated both in the extraction and processing phase [15]. This thereby addresses the need for alternatives.

In recent years, bio construction has been widely used because of its long-term viability and versatility compared to conventional construction [16]. Bio-based materials such as wood, bamboo, hemp, cork, straw, and flax are used for structural and non-structural applications. Due to its ability to store carbon and the fact that it may be recycled or biodegraded, it has a less negative impact on the environment [17]. Additionally, its hygrothermal properties also show even larger dynamics [18]. Bio-based building materials (BBMs) may be an alternative option for CMs, according to research findings to date. However, these materials' potential impacts on human health and wellbeing are also a source for worry.

Despite the significant studies on wellbeing, environmental and economic impacts, thermophysical properties…, less academic research focused on the potential health effects of construction materials in general to the best of our knowledge [15], [19-21]. Fewer studies have specifically examined the effects of BBMs on health and wellbeing. Since it's challenging to properly evaluate a person's wellbeing condition [22].

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Nevertheless, it's necessary to conduct further investigations.

2 Methodology

This paper aims to look through the potential health and wellbeing impacts of BBMs. Which aims to provide a comprehensive review of the relevant scientific research. It was initially accomplished by using manual methods for searching, verifying, and selecting scientific papers. The key terms used in this step are: "bio-based construction materials" AND "health impacts" OR "wellbeing". Scientific databases, including google scholar, ScienceDirect, and Web of Science were used. Thereafter, the snowball backward method was used to find other pertinent studies [23]. The general inclusion criteria are defined to review relevant publications that are within the scope of BBMs health impacts and related terms discussed previously. Particularly, English-language studies that used experimental results to assess the effects of BBMs.

In a comprehensive review, the chosen studies were summarized, interpreted, and organized into sections depending on the various aspects of their effects on health and wellbeing. Both positive and negative health impacts were considered.

3 Positive and negative impacts on IEQ

3.1 Thermal comfort

Since thermal comfort also affects sleep quality [24], cardiovascular [25] and respiratory health [26], careful consideration should be given to choosing construction materials that can control moisture and temperature levels. Studies comparing BBMs with CMs have shown encouraging results, however they are conditional and subject to specific requirements. Notably, Bio-concrete was investigated [27] for its advantages and disadvantages on human health as Fig.1 show the impacts of bio-concrete as a material and after its use reported in reviewed articles.

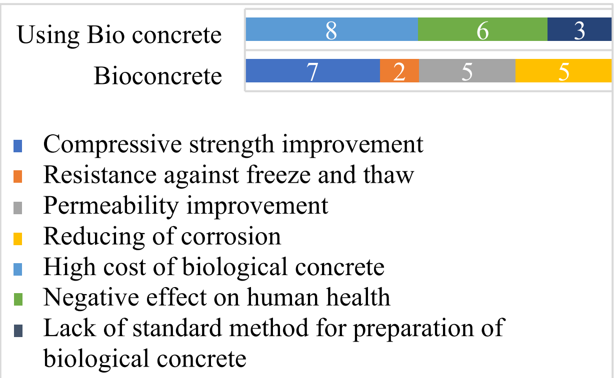

Fig. 1. Number of reviewed articles in regards of negative and positive impacts of Bioconcrete [27].

The benefits of certain bacteria species, including *Bacillus pasteurii*, *Bacillus sphaericus*, and *Bacillus lentus*, on water absorption and concrete strength were highlighted. However, it is crucial to consider the adverse effects linked to using *Pseudomonas aeruginosa* on human immune systems in residential and administrative constructions. Other materials including Hempcrete, Flax concrete, and Straw rape concrete under varying temperature and moisture conditions, showed that they possess a good heat storage capacity and low thermal conductivity, making them excellent thermal insulators [28]. Similarly, Hempcrete [29] were the subject of another experiment of heat transfer and moisture. Higher relative humidity above 95 % and temperatures led to increased rates of moisture exchange. Which can worsen indoor air quality and human health above this range by creating favourable conditions for Mold development and material degradation in humid environments. Nevertheless, a study conducted under real conditions for 2 years on a hempcrete single dwelling-house shows positive outcomes in terms of buffering moisture and damping temperatures fluctuations with an 11-hour time-shift [30]. This implies that hempcrete could potentially appropriate for usage in areas with significant temperature changes.

For Insulation and coatings, various materials were examined, and showed positive impacts on thermal comfort so far. some materials include wool and sawdust [31], Bio-clay plaster [32] and Mycelium-based composites (MBC) [33] exhibited moisture absorption and desorption capabilities, making them potential alternatives for moisture buffering applications. While the negative aspect of straw-based materials compared to cotton-based mycelium composites was that its stiffness and less moisture-resistance, yet mechanical properties of MBC can be improved by heat pressing. Whilst hempcrete, Hemp/PHB composites demonstrated superior resistance to moisture absorption than hemp/cellulose acetate composites in humid conditions (100% RH at variant Temperatures) in another examination of moisture diffusion and tensile behaviour [34]. These findings highlight the potential of these materials for various applications, particularly in high-moisture environments. Thus, it is crucial to guarantee effective control of moisture and ventilation in buildings made of BBMs in order to mitigate Mold growth and moisture-related concerns.

3.2 Acoustic comfort

Noise pollution has various effects on human health and well-being, including poor learning performance, potential hearing loss, anxiety, stress [35], and insomnia. comparing acoustic properties is difficult due to frequency variations [36]. However, bio-based materials have demonstrated sound absorption efficiency [37] considering material-specific requirements. For example, achieving the best acoustic results using hempcrete [38-40] , requires considering more the conditions of installation, the content of binders and the density. Various Biocomposite insulation materials, such as light earth, straw-lime, hempcrete, and olive pit mixes [41], recycled textile waste and biopolymers [42], as well as biofibre-based acoustic coatings [43], have the characteristics of less carbon-based acoustic materials.

4 Positive and negative impacts on IAQ

IAQ get affected by indoor pollutants linked to construction materials including BBMs in addition to human activities, household products…etc. Common indoor air pollutants, including Formaldehyde (HCHO), VOC, Total Volatile Organic Compounds (TVOC), semi-volatile organic compounds ((S)VOC), Plastic Compounds (PC), Asbestos, Lead, Particulate Matter (PM), Silica, Polybrominated Diphenyl Ethers (PBDEs). Some of these pollutants are presented in table 1. A study provided the health impacts linked with TVOC values, as seen in table 2.

Table 1. Indoor pollutants related to building materials [44].

Pollutants	Sources	Impacts	Ref.
HCHO	Wood-based materials, that includes urea-formaldehyde resins	Eye, nose, throat irritation, asthma, bronchitis, and possible carcinogen	[7] [45]
VOC	Flooring systems, paints, and adhesives	Asthma, bronchial hyper-reactivity	[46-48]
PC	Polyvinyl chloride for flooring, plastic	Bronchial obstruction, asthma, wheeze, cough, and phlegm	[49]

Table 2. Health impacts of TVOC [50].

Values of TVOC	Impacts
< 200 µg m-3	No irritation or discomfort is expected.
200 – 3,000 µg m-3	Irritation or discomfort may occur.
3,000 – 25,000 µg m-3	Discomfort is expected and headache is possible
> 25,000 µg m-3	The toxic range where other neurotoxic effects may occur

4.1 Indoor pollutants and BBMs

The total VOC levels that need to be controlled were presented in a study by Molhave and al [50]. Several experimental studies explored VOC, TVOC, (S)VOC or/and formaldehyde emissions of different BBMs. The majority indicated that BBMs have less emissions in comparison with traditional ones. These comparisons included those between Lime-based building materials and cement-based ones in terms of lower VOC emissions, where cement-based materials showed high VOC emissions, primarily dominated by neopentyl glycol, an additive commonly used in industry [51]. Other study investigated Calcium silicate board, green calcium silicate board, mineral fibre ceiling, green mineral fibre ceiling, gypsum board, green gypsum board, wooden flooring, where green building materials had less emissions, especially to gypsum board and wooden flooring [52]. Other research focused on Hybrid bio-based biocomposite (kenaf-OPF hybrid PHB biocomposite) to glass fibre reinforced polypropylene and glass fibre reinforced polyethylene composites [53]. It was confirmed that Hybrid bio-based biocomposite helps reduce indoor impacts on human health. Further research confirmed BBMs' potential to provide better indoor air quality with lower toxic emissions compared to traditional materials. These studies included insulation materials and earthen dry boards and plasters [54], wood-based materials [55], Green building materials GBMs [56], Cellulose flakes, Wool, Hemp fibre, Wood fibre, Hemp lime 275 kg/m3 mix, Hemp lime 330 kg/m3 mix, Rigid wood fibre board [57], Recycled carpet, perlite-based ceiling tile, and low-VOC paint and primer [58], sunflower-based insulation panels [59].

5 Psychological health and well-being

The psychological effects of being or living in a certain environment are a significant consequence that are frequently overlooked in the modern era. Even thought, it’s an objective matter which can have different psychological effects from person to another. Thus, limited number of studies have demonstrated the connection between construction materials generally used in a building and people's mental health [15],[20]. However, some of the research studies contain relevant insights of using BBMs on the possible effects on psychological wellbeing. In particular, a study focused on interior wooden materials [60]. These materials have been proven to have advantages regarding sustainability, human wellbeing. In addition to the effects on mental health associated with materials characteristics mentioned previously, these nature sourced materials promote the principles of biophilic design [61]. The concept Biophilic design aims to use natural elements to create healthy environment that enhance well-being, and health [62,63]. This can include features like natural daylighting, outdoor views, and natural ventilation [64]. A negative impact highlighted in a survey dated to 2015 that people hesitate to pay more money for using biological concrete in their office or house [27]. Table 3 presents summary of the positive and negative impacts related to bio-based materials.

Table 3. Summary of the positive and negative impacts related to bio-based materials.

Positive impacts	**Ref.**	**Negative impacts**	**Ref.**
Thermal comfort			
Regulating temperature and humidity levels.	[28-33]	The use of *Pseudomonas aeruginosa* in residential and occupational structures has negative effects on human health when incorporated into bio concrete.	[27]
The use of *Bacillus pasteurii, Bacillus sphaericus,* and *Bacillus lentus* bacteria for self-healing concrete production.	[27]	Relative humidity above 95% and temperatures may create Mold growth and material degradation	[29]
Hempcrete, Flax concrete, and Straw rape concrete have commendable heat storage capacity and low thermal conductivity, making them as excellent thermal insulators.	[28]	/	/
- Hempcrete has capacity of buffering moisture and dampening temperature fluctuations, making it a potential choice for areas with significant temperature changes. - Hempcrete and Hemp/PHB composites have demonstrated superior resistance to moisture absorption compared to hemp/cellulose acetate composites, further reinforcing their suitability for humid conditions.	[29] [34]	/	/
Wool and sawdust, Bio-clay plaster, and Mycelium-based composites (MBC), have exhibited moisture absorption and desorption capabilities, showcasing positive impacts on thermal comfort	[31-33]	/	/
Acoustic performance			
Sound absorption efficiency of materials such as Light earth, straw-lime, hempcrete, olive pit mixes, recycled textile waste, biopolymers, and biofibre-based acoustic coatings	[37-43]	Due to frequency variances, it is challenging to compare different materials' acoustic properties precisely. This may make it more difficult to decide which acoustic material is best for a given application or environment.	[36]
IAQ			
Lower emissions of VOCs, TVOCs, S-VOCs, and formaldehyde compared to traditional building materials. This imply that BBMs can contribute to improved indoor air quality and reduce potential health risks associated with indoor pollutants.	[51-59]	/	/
Psychological health and well-being			
The use of BBMs, particularly interior wooden materials, can align with the principles of biophilic design.	[60-61]	People hesitate to pay more money for using biological concrete in their office or house.	[27]

6 Implications and future perspective

The main barrier that bio-based materials can face is convincing consumers to use it instead of conventional ones. Hence, traditional materials are cheaper while bio-based materials have lower toxic emissions [52]. Thus, the promotion of such materials can be successful, if the focus is on the price, health advantages, and policy initiatives. Future perspective for the health and wellness effects of newly produced BBMs are encouraging as long as their use helps construct healthier buildings within the regulations and the initiatives.

6 Conclusion

Most of the reviewed studies showed that bio-based building materials has more favourable effects than using traditional construction materials in terms of improved indoor environment quality, lower toxic emissions, thermal and acoustic comfort, and creating a connection with nature. Given that there is no completely risk-free bio-based material, it is essential to look for the material that poses least health hazards when considering it. The findings imply that Further studies is required to determine the optimal use without compromising health and human wellbeing. Further investigation may be required to fully cover the limitations of the literature and the knowledge gaps found in this paper.

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