Research paper

Check for updates

Archimane, 2026, Vol. 4, No. 2, 139–150
DOI: 10.59810/archimane/v4i2.271
ISSN 2987-1131 (online); 2987-4033 (print)

Evaluating the Sustainability of Mineral Wool Use in Room Acoustic Improvements

Frengky Benediktus Ola | Universitas Atma Jaya Yogyakarta, Indonesia

Abstract

Porous materials are widely used to improve room acoustics, particularly where greater speech intelligibility and control of reverberation time are required. Mineral wool is among the most commonly used materials because of its acoustic performance and availability. However, its evaluation often emphasizes technical performance without fully considering sustainability. This study compares mineral wool with other porous materials using three sustainability indicators: carbon footprint, embodied energy, and toxicity. It also examines the environmental implications of mineral wool use and substitution in practical acoustic interventions. A comparative literature review was used to establish the sustainability profile of mineral wool. The findings were then applied to five case-study rooms in which mineral wool had been installed as part of an acoustic improvement system. For each case, the additional carbon footprint and embodied energy of the installed mineral wool were calculated and compared with substitution scenarios involving materials with equivalent acoustic functions. Toxicity was assessed through literature concerning potential health risks and indoor air quality. The analysis examines differences in environmental impact and potential health risks among materials and changes in room-level sustainability resulting from substitution. By integrating literature review with case-based calculations, the study proposes a sustainability-oriented framework for evaluating porous acoustic materials to inform material selection for room acoustic treatment.

Keywords: Carbon footprint, embodied energy, mineral wool, room acoustics, sustainability, toxicity

Article history:
Received July 24, 2026
Received in revised form August 19, 2026
Accepted Sept. 20, 2026
Available online October 31, 2026

Correspondence address:
Frengky Benediktus Ola, Department of Architecture, Faculty of Engineering, Universitas Atma Jaya Yogyakarta, Jl. Babarsari No. 43, Yogyakarta, Indonesia
Email: frengky.ola@uajy.ac.id

Copyright ©2026 Frengky Benediktus Ola. This is an open access article distributed the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

Introduction

Sustainability has become a central principle in contemporary building design and construction. It concerns both efficient resource use and the reduction of environmental impacts throughout a building's life cycle, from material selection and production to construction, use, and demolition. Design decisions therefore extend beyond technical and aesthetic considerations to include environmental sustainability, energy efficiency, and occupants' quality of life. Construction materials should be understood both as components of spatial form and as sources of ecological and health consequences. Embodied energy and carbon footprint are widely used indicators of material sustainability because they represent the energy consumption and emissions associated with processes from raw-material extraction to use in a building (Asdrubali et al. 2023; Estrada and Lee 2023; Morini, Ribeiro, and Hotza 2019).

Embodied energy and carbon footprint are important parameters for assessing the environmental effects of construction materials. Embodied energy represents the total energy required across material production processes, whereas carbon footprint describes the greenhouse gas emissions associated with a material's life cycle. These indicators matter because technical performance does not necessarily imply favorable sustainability performance. A material that performs its intended function efficiently may still require substantial production energy or generate considerable carbon emissions. Understanding both indicators supports more responsible design decisions consistent with sustainability principles (Kaynak, Piri, and Das 2025).

Material toxicity also requires attention in sustainability assessment. It refers to the potential for materials to harm users, workers, or the environment through mechanisms such as particle release, hazardous emissions, and effects on indoor air quality. The literature describes exposure through inhalation, ingestion, skin contact, and environmental contamination, with risks associated with both conventional materials, such as heavy metals, and newer materials, such as nanomaterials and microplastics. Reported toxic effects range from acute skin irritation and respiratory symptoms to chronic outcomes such as cancer, neurodegenerative disease, and reproductive dysfunction. In buildings, technically effective materials may nevertheless diminish environmental quality if they create irritation, hazardous emissions, or exposure risks. Material sustainability should therefore include short- and long-term safety alongside resource efficiency and carbon emissions. Toxicity assessment helps determine whether construction materials can fulfill their intended functions while supporting a healthy indoor environment (Gulzar, Hassan, and Gulzar 2021; Arar, Jung, and Qassimi 2022; Mishra, Sudarsan, and Nithiyanantham 2025).

Mineral wool is widely used in room acoustic treatment. Sound absorbers are commonly divided into three categories: panel absorbers, cavity absorbers, and porous absorbers. The manuscript considers mineral wool an important component in achieving the performance of these systems.

Its sound absorption, ease of installation, and availability in various products make it a common choice for interior acoustic systems. Applications include wall and ceiling panels, partitions, and absorptive elements in spaces requiring reverberation control and improved speech intelligibility, such as auditoriums, places of worship, meeting rooms, and classrooms. However, widespread use has not always been accompanied by sufficient assessment of carbon footprint, embodied energy, and toxicity. Acoustic material evaluation therefore needs to consider environmental and health implications as well as sound performance.

This study reviews the sustainability profile of mineral wool in room acoustic treatment and evaluates the environmental implications of its use. It combines a comparative literature review with calculations for several case-study rooms, allowing theoretical findings to be considered alongside their implications at room scale. The aim is to provide a more comprehensive basis for selecting acoustic materials that are technically effective and consistent with sustainability principles.

Methods

The study combines a comparative literature review with case-study analysis to assess the sustainability of mineral wool in the acoustic improvement of worship spaces. It focuses on embodied energy, carbon footprint, and toxicity. Literature was used to establish technical and environmental parameters, which were then applied to four worship spaces that had undergone acoustic interventions.

The cases comprise four Christian worship spaces in Indonesia: Maria Marganingsih Church in Kalasan, St. Pius X Church in Karanganyar, St. Theresia Church in Sedayu, and GKE Imanuel Church in Central Kalimantan. They were selected for their different room volumes, enabling a comparison of mineral wool's environmental contribution across spatial scales. Data were drawn from scientific literature, life cycle assessment publications, and technical information on mineral wool.

The calculations used literature-based values for mineral wool's embodied energy and carbon emissions associated with production and distribution. These values were combined with the material quantities required in each room to estimate total embodied energy and carbon footprint. The results were compared across cases to examine the relationship between room volume and environmental burden. Toxicity was evaluated descriptively using literature on modern mineral wool fibers, exposure pathways, and health implications. The analysis is limited to mineral wool and excludes supporting materials such as frames, boards, adhesives, and screws.

Results and discussion

Carbon footprint of Mineral Wool

Mineral wool production is energy intensive because raw materials such as basalt or slag must be melted at high temperatures. Reported production-stage emissions range from approximately 90 to 167 kg CO_2 per m^3, while some studies report values as high as 1,471.77 kg CO_2-eq per tonne of rock wool board. Much of the burden arises from raw-material extraction and melting. Life cycle assessment studies indicate that, despite substantial initial embodied carbon, mineral wool used in building envelopes can generate significant operational energy savings for heating, ventilation, and air conditioning over time. One study reports an environmental payback period of approximately seven years, after which reduced heating and cooling demand yields net greenhouse gas savings (Adamczyk, Harat, and Grmela 2016; Komorowska et al. 2023; Huang and Zhang 2020; Alam, Picco, and Resalati 2022; Fořt, Maděra, and Černý 2019; Llantoy, Chàfer, and Cabeza 2020).

Comparing the carbon footprint of mineral wool with alternative porous acoustic materials has become an important area of sustainable-building research. Mineral wool, including rock wool and glass wool, is widely used for acoustic and thermal performance, but its production is energy intensive and associated with substantial CO_2 emissions. Research has examined bio-based alternatives, including sheep wool, cellulose, coconut fiber, and recycled materials, to reduce environmental impact while retaining performance. Life cycle assessments report that substituting natural fibers or recycled materials for mineral wool can reduce partition-level carbon footprints by 4–6% and material-level carbon footprints by 70–85%. Bio-based absorbers such as sheep wool and cellulose may also offer biodegradability and indoor air quality benefits (Bousshine et al. 2022; Mohammadi et al. 2024; Prabhune et al. 2022; Quintana-Gallardo et al. 2020; Kabun and Reinhold 2025)

Embodied energy of Mineral Wool

Mineral wool, including stone wool, glass wool, and slag wool, is widely used in building acoustics for its sound absorption and fire resistance. As sustainability receives greater attention, the embodied energy of insulation materials is increasingly assessed alongside their operational benefits. Recent literature and environmental product declarations provide comparisons with alternatives such as expanded polystyrene (EPS), polyurethane foam, cellulose, and bio-based products. Although mineral wool offers competitive acoustic performance and durability, high-temperature manufacturing remains energy intensive (Asdrubali, D'Alessandro, and Schiavoni 2015; Grazieschi, Asdrubali, and Thomas 2021; Lu et al. 2024).

A critical review of 223 values from environmental product declarations reported competitive embodied impacts for conventional inorganic insulation materials:

- Glass wool: 16–31 MJ per functional unit (FU), defined as 1 m^2 with a thermal resistance of R = 1 m^2 K/W.

- Stone wool: 21–66 MJ/FU

These values are generally lower than those reported for fossil-based insulation such as EPS (44–78 MJ/FU) or advanced aerogels (251–372 MJ/FU). Density is an important determinant of embodied energy for glass wool, stone wool, and EPS (Grazieschi, Asdrubali, and Thomas 2021).

When assessed by mass or an appropriate functional unit, mineral wool often performs better than hydrocarbon-based insulation in embodied energy and global warming potential (GWP). Bio-based insulation may have lower GWP but sometimes requires greater thickness to achieve comparable acoustic or thermal performance. The literature generally reports competitive or lower embodied energy for mineral wool relative to many synthetic alternatives on a functional-unit basis. However, variations in system boundaries and density assumptions complicate direct comparison among studies. Bio-based insulation can benefit from carbon uptake during growth, but may require greater thickness or have less well-characterized durability. Mineral wool recycling initiatives are emerging but remain limited; broader implementation could further reduce life cycle impacts. For mineral wool, production is described as the principal environmental burden, whereas raw-material sourcing can be more influential for organic insulation (Grazieschi, Asdrubali, and Thomas 2021; Hill, Norton, and Dibdiakova 2018; Lu et al. 2024; Füchsl, Rheude, and Röder 2022).

Toxicity of Mineral Wool

Stone wool, glass wool, and slag wool are widely used as insulation in construction and industry. Their fibrous nature has prompted continuing toxicity research and concerns comparable to those raised for asbestos. Recent studies describe modern mineral wool as designed for greater biosolubility and lower biopersistence, reducing potential health risks. Occupational exposure primarily involves inhalation of respirable fibers and dust. The reviewed evidence indicates low carcinogenic potential for most modern products while emphasizing continued monitoring, particularly for older materials manufactured before changes in safety requirements. Skin irritation is common but usually mechanical rather than allergic. Although environmental and human toxicity is described as low under typical use conditions, high occupational exposures and improper waste handling warrant caution and further study (Kupczewska-Dobecka, Konieczko, and Czerczak 2020; Sattler et al. 2020; De Vuyst et al. 1995; Björnberg and Löwhagen 1977; Jolanki et al. 2002; Stam‐Westerveld et al. 1994).

Occupational exposure to respirable mineral wool fibers can present risks when fiber dimensions permit deep lung penetration, particularly at diameters below 3 µm. However, the epidemiological evidence reviewed does not show a strong association between modern glass, stone, or slag wool exposure and pulmonary fibrosis or mesothelioma. Some studies report slightly elevated lung cancer risk among workers exposed during earlier production periods when other carcinogens may also have been

present. The manuscript describes modern products meeting biosolubility criteria as generally classified as non-carcinogenic (Kupczewska-Dobecka, Konieczko, and Czerczak 2020; Sattler et al. 2020; De Vuyst et al. 1995).

The reviewed literature generally reports low acute and chronic toxicity for modern mineral wool under typical use conditions. The shift toward biosoluble fiber compositions has reduced biopersistence, an important determinant of pathogenicity, and consequently reduced long-term respiratory risk relative to earlier formulations or asbestos-like materials. Nevertheless, high-dust workplaces and the handling of older materials can pose respiratory and skin-irritation risks. Compliance with safety guidance, including personal protective equipment, can reduce exposure (Hesterberg and Hart 2001; Wohlleben et al. 2017; Kopytenkova et al. 2018; Kupczewska-Dobecka, Konieczko, and Czerczak 2020).

Case-Based assessment of Mineral Wool sustainability

Acoustic improvements in church buildings affect both listening conditions and the environment. Added materials, altered interior elements, and associated construction work can increase embodied energy and carbon emissions. The following analysis therefore considers energy and emissions as part of the sustainability assessment of acoustic interventions. Comparing four church cases illustrates how acoustic performance improvements can add to construction-related environmental burdens.

The four study spaces are Christian worship rooms in Indonesia (figure 1). In descending order of volume, they are Maria Marganingsih Church in Kalasan, St. Pius X Church in Karanganyar, St. Theresia Church in Sedayu, and GKE Imanuel Church in Central Kalimantan. The ordering reflects the assumption that larger volumes require more extensive acoustic treatment, increasing treated surface area and mineral wool quantities. The installed acoustic systems include panel, cavity, and porous absorbers.

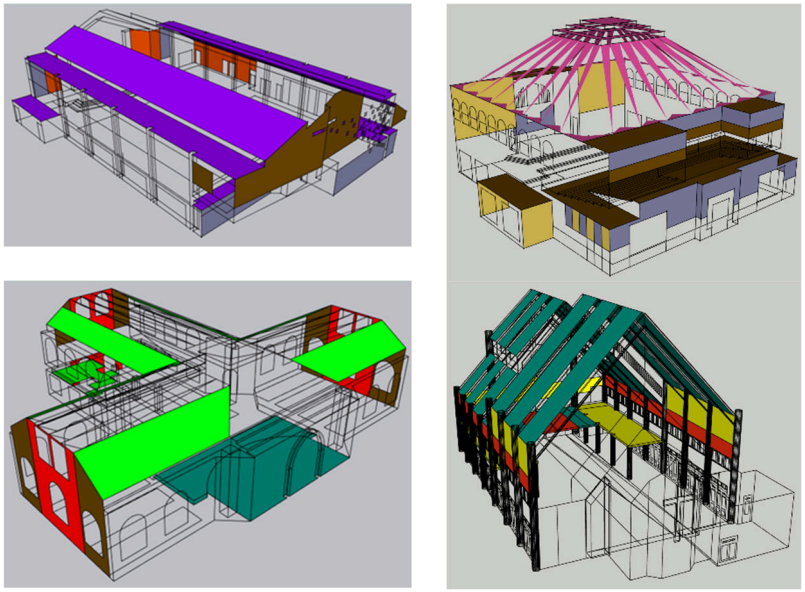


Figure 1
Acoustic material layouts in the four cases, clockwise: Maria Marganingsih Church, St. Pius X Church, St. Theresia Church, and GKE Emanuel Church

The literature review identified an embodied energy value of 66 MJ for each square meter of mineral wool at a thickness of one inch. Production and distribution of the same area were associated with 4.2 kg CO_2-eq. Figure 2 compares room volume with the embodied energy and emissions of the mineral wool used for acoustic treatment. Larger volumes were associated with greater environmental contributions. Maria Marganingsih Church accounted for 69,630 MJ of embodied energy and 4,431 kg CO_2-eq. For the smallest space, GKE Emanuel Church in Central Kalimantan, the source reports 26.00 MJ of embodied energy and 1,680 kg CO_2-eq. Across the four cases, the reported average was 6.77 MJ per cubic meter of room volume. The manuscript compares this energy quantity with three hours of jogging, bringing 20 liters of water to the boil, or sleeping for 27 hours. Average carbon emissions were 0.43 kg CO_2-eq per cubic meter, compared in the manuscript with driving three kilometers or charging a mobile phone 70 times. These calculations include only mineral wool and exclude supporting components required for functioning acoustic assemblies, such as galvanized steel frames, perforated gypsum boards, plywood, timber or wood–plastic composite, heavy fabric, adhesives, and screws.

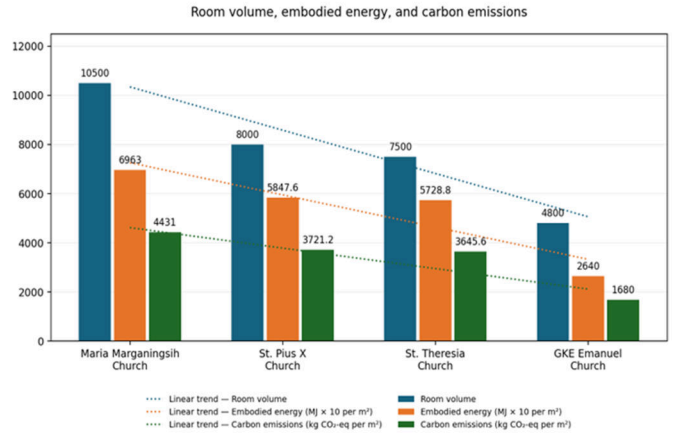


Figure 2
Comparison of room volume with embodied energy and emissions associated with mineral wool

Although the reviewed studies describe modern mineral wool as having relatively low toxic potential, construction practices that neglect workers' long-term health can still produce adverse outcomes. Research on alternative porous acoustic materials reports several findings. Natural fibers, including hemp, kenaf, wood fiber, coconut fiber, and sheep wool, are increasingly studied for their low toxicity profiles. Reviews describe these materials as not causing skin or respiratory irritation under normal use conditions. Recycled textiles, such as denim and mixed-textile panels, can provide sound absorption comparable to mineral wool, with more favorable environmental performance and no reported adverse health effects during handling or installation in the studies reviewed. Life cycle assessments generally indicate lower environmental impacts for natural-fiber and recycled-textile insulation, reflecting lower production energy and easier end-of-life disposal (Prabhune et al. 2022; Yang et al. 2020; Asdrubali, D'Alessandro, and Schiavoni 2015; Islam and Bhat 2019; Szczecina et al. 2026).

Conclusion

Mineral wool used in the acoustic improvement of worship spaces contributes to sound performance while also introducing embodied energy and carbon emissions. Across the cases, larger room volumes were associated with greater material requirements and environmental burdens. The reported mean values were approximately 6.77 MJ of embodied energy and 0.43 kg CO_2-eq per cubic meter of room volume. Acoustic interventions should therefore be considered technical measures with environmental consequences.

The literature reviewed describes modern mineral wool as having relatively low toxicity under normal use conditions, while emphasizing occupational safety, appropriate handling, and waste management. Bio-based or recycled alternatives may reduce environmental burdens, provided their acoustic performance and technical suitability

are considered. Material selection should therefore assess energy, emissions, and health implications alongside sound absorption so that sustainability can be integrated into building design.

Further research could include all acoustic-system components, such as frames, facing boards, adhesives, and supporting elements. Direct comparison of mineral wool with bio-based or recycled alternatives using a more comprehensive life cycle assessment would strengthen the practical relevance of the findings.

References

Adamczyk, Zdzisław, Andrzej Harat, and Arnost Grmela. 2016. "Application of REACH and LCA System's to the Materials Formed in the Production of Mineral Wool." *Chemistry-Didactics-Ecology-Metrology* 21 (1–2): 125–32. https://doi.org/10.1515/cdem-2016-0011.

Alam, Mahmood, Marco Picco, and Shahaboddin Resalati. 2022. "Comparative Holistic Assessment of Using Vacuum Insulated Panels for Energy Retrofit of Office Buildings." *Building and Environment* 214 (April):108934. https://doi.org/10.1016/j.buildenv.2022.108934.

Arar, Mohammad, Chuloh Jung, and Nahla Al Qassimi. 2022. "Investigating the Influence of the Building Material on the Indoor Air Quality in Apartment in Dubai." *Frontiers in Built Environment* 7 (January). https://doi.org/10.3389/fbuil.2021.804216.

Asdrubali, Francesco, Francesco D'Alessandro, and Samuele Schiavoni. 2015. "A Review of Unconventional Sustainable Building Insulation Materials." *Sustainable Materials and Technologies* 4 (July):1–17. https://doi.org/10.1016/j.susmat.2015.05.002.

Asdrubali, Francesco, Gianluca Grazieschi, Marta Roncone, Francesca Thiebat, and Corrado Carbonaro. 2023. "Sustainability of Building Materials: Embodied Energy and Embodied Carbon of Masonry." *Energies* 16 (4): 1846. https://doi.org/10.3390/en16041846.

Björnberg, A, and GB. Löwhagen. 1977. "Patch Testing with Mineral Wool (Rockwool)." *Acta Dermato-Venereologica* 57 (3): 257–60. https://doi.org/10.2340/0001555557257260.

Bousshine, Said, Mohamed Ouakarrouch, Abdelmajid Bybi, Najma Laaroussi, Mohammed Garoum, and Amine Tilioua. 2022. "Acoustical and Thermal Characterization of Sustainable Materials Derived from Vegetable, Agricultural, and Animal Fibers." *Applied Acoustics* 187 (February):108520. https://doi.org/10.1016/j.apacoust.2021.108520.

Estrada, Hector, and Luke Lee. 2023. "Embodied Energy and Carbon Footprint of Concrete Compared to Other Construction Materials." *Athens Journal of Technology & Engineering* 10 (2): 107–22. https://doi.org/10.30958/ajte.10-2-2.

Fořt, Jan, Jiří Maděra, and Robert Černý. 2019. "Monetized Environmental Assessment of Interior Thermal Insulation." Edited by R. Černý, J. Kočí, and V. Kočí. *MATEC Web of Conferences* 282

(September):02106. https://doi.org/10.1051/matecconf/201928202106.

Füchsl, Stefan, Felix Rheude, and Hubert Röder. 2022. "Life Cycle Assessment (LCA) of Thermal Insulation Materials: A Critical Review." *Cleaner Materials* 5 (September):100119. https://doi.org/10.1016/j.clema.2022.100119.

Grazieschi, Gianluca, Francesco Asdrubali, and Guilhem Thomas. 2021. "Embodied Energy and Carbon of Building Insulating Materials: A Critical Review." *Cleaner Environmental Systems* 2 (June):100032. https://doi.org/10.1016/j.cesys.2021.100032.

Gulzar, Aadil, Tabasum Hassan, and Ruquia Gulzar. 2021. "Potentially Toxic Construction Materials: An Introduction." In *Ecological and Health Effects of Building Materials*, 1–11. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-76073-1_1.

Hesterberg, Thomas W., and Georgia A. Hart. 2001. "Synthetic Vitreous Fibers: A Review of Toxicology Research and Its Impact on Hazard Classification." *Critical Reviews in Toxicology* 31 (1): 1–53. https://doi.org/10.1080/20014091111668.

Hill, Callum, Andrew Norton, and Janka Dibdiakova. 2018. "A Comparison of the Environmental Impacts of Different Categories of Insulation Materials." *Energy and Buildings* 162 (March):12–20. https://doi.org/10.1016/j.enbuild.2017.12.009.

Huang, Meng Chi, and Yan Jiao Zhang. 2020. "Carbon Emissions Analysis of Rock Wool Board Products." *Materials Science Forum* 993 (May):1545–51. https://doi.org/10.4028/www.scientific.net/MSF.993.1545.

Islam, Shafiqul, and Gajanan Bhat. 2019. "Environmentally-Friendly Thermal and Acoustic Insulation Materials from Recycled Textiles." *Journal of Environmental Management* 251 (December):109536. https://doi.org/10.1016/j.jenvman.2019.109536.

Jolanki, Riitta, Ilpo Mäkinen, Katri Suuronen, Kristiina Alanko, and Tuula Estlander. 2002. "Occupational Irritant Contact Dermatitis from Synthetic Mineral Fibres According to Finnish Statistics." *Contact Dermatitis* 47 (6): 329–33. https://doi.org/10.1034/j.1600-0536.2002.470602.x.

Kabun, Katrin, and Karin Reinhold. 2025. "Improving Indoor Air Quality and Mitigating Health Risks with Sheep Wool as a Sustainable Material." *Indoor Environments* 2 (3): 100111. https://doi.org/10.1016/j.indenv.2025.100111.

Kaynak, Elif, Imelda Saran Piri, and Oisik Das. 2025. "Revisiting the Basics of Life Cycle Assessment and Lifecycle Thinking." *Sustainability* 17 (16): 7444. https://doi.org/10.3390/su17167444.

Komorowska, Monika, Marcin Niemiec, Jakub Sikora, Zofia Gródek-Szostak, Hatice Gurgulu, Maciej Chowaniak, Atilgan Atilgan, and Pavel Neuberger. 2023. "Evaluation of Sheep Wool as a Substrate for Hydroponic Cucumber Cultivation." *Agriculture* 13 (3): 554. https://doi.org/10.3390/agriculture13030554.

Kopytenkova, Olga I., Z. Sh. Tursunov, A. V. Levanchuk, O. V. Mironenko, N. M. Frolova, and A. M. Sazonova. 2018. "The Hygienic Assessment of the Working Environment in Individual Occupations in Building

Organizations." *Hygiene and Sanitation* 97 (12): 1203–9. https://doi.org/10.18821/0016-9900-2018-97-12-1203-1209.

Kupczewska-Dobecka, Małgorzata, Katarzyna Konieczko, and Sławomir Czerczak. 2020. "Occupational Risk Resulting from Exposure to Mineral Wool When Installing Insulation in Buildings." *International Journal of Occupational Medicine and Environmental Health* 33 (6): 757–69. https://doi.org/10.13075/ijomeh.1896.01637.

Llantoy, Noelia, Marta Chàfer, and Luisa F. Cabeza. 2020. "A Comparative Life Cycle Assessment (LCA) of Different Insulation Materials for Buildings in the Continental Mediterranean Climate." *Energy and Buildings* 225 (October):110323. https://doi.org/10.1016/j.enbuild.2020.110323.

Lu, Zheng, Michael Hauschild, Lisbeth M. Ottosen, Teklit Gebregiorgis Ambaye, Pierluigi Zerbino, Davide Aloini, and Ana T. Lima. 2024. "Climate Mitigation Potential of Biobased Insulation Materials: A Comprehensive Review and Categorization." *Journal of Cleaner Production* 470 (September):143356. https://doi.org/10.1016/j.jclepro.2024.143356.

Mishra, A. K., J. S. Sudarsan, and S. Nithiyanantham. 2025. "Toxicological Analysis of Building Materials to Determine the Effects of Sick Building Syndrome on Occupants and Construction Workers." *Journal of Umm Al-Qura University for Engineering and Architecture* 16 (2): 225–36. https://doi.org/10.1007/s43995-025-00096-2.

Mohammadi, Majid, Ebrahim Taban, Wei Hong Tan, Nazli Bin Che Din, Azma Putra, and Umberto Berardi. 2024. "Recent Progress in Natural Fiber Reinforced Composite as Sound Absorber Material." *Journal of Building Engineering* 84 (May):108514. https://doi.org/10.1016/j.jobe.2024.108514.

Morini, Antonio Augusto, Manuel J. Ribeiro, and Dachamir Hotza. 2019. "Early-Stage Materials Selection Based on Embodied Energy and Carbon Footprint." *Materials & Design* 178 (September):107861. https://doi.org/10.1016/j.matdes.2019.107861.

Prabhune, Savani, Yashwant Munde, Avinash Shinde, and I. Siva. 2022. "Appraising the Acoustic Performance and Related Factors of Natural Fiber: A Review." *Journal of Natural Fibers* 19 (16): 13475–94. https://doi.org/10.1080/15440478.2022.2099500.

Quintana-Gallardo, Alberto, Jesús Alba, Romina del Rey, José E. Crespo-Amorós, and Ignacio Guillén-Guillamón. 2020. "Life-Cycle Assessment and Acoustic Simulation of Drywall Building Partitions with Bio-Based Materials." *Polymers* 12 (9): 1965. https://doi.org/10.3390/polym12091965.

Sattler, Theresa, Roland Pomberger, Julia Schimek, and Daniel Vollprecht. 2020. "Mineral Wool Waste in Austria, Associated Health Aspects and Recycling Options." *Detritus*, no. 9 (February), 174–80. https://doi.org/10.31025/2611-4135/2020.13904.

Stam-Westerveld, E. B., P. J. Coenraads, P. G. M. Van Der Valk, M. C. M. De Jong, and V. Fidler. 1994. "Rubbing Test Responses of the Skin to Man-made Mineral Fibres of Different Diameters." *Contact Dermatitis* 31 (1): 1–4. https://doi.org/10.1111/j.1600-0536.1994.tb01894.x.

Szczecina, Julita, Ewa Szczepanik, Jakub Barwinek, Piotr Szatkowski, Marcin Niemiec, and Edyta Molik. 2026. “Valorisation of Sheep Wool Fibers in Sustainable Energy-Efficient Materials: Thermal and Acoustic Properties of Bio-Based Composites for Low-Carbon Construction.” *Energies* 19 (3): 866. https://doi.org/10.3390/en19030866.

Vuyst, P De, P Dumortier, GM Swaen, JC Pairon, and P Brochard. 1995. “Respiratory Health Effects of Man-Made Vitreous (Mineral) Fibres.” *European Respiratory Journal* 8 (12): 2149–73. https://doi.org/10.1183/09031936.95.08122149.

Wohlleben, Wendel, Hubert Waindok, Björn Daumann, Kai Werle, Melanie Drum, and Heiko Egenolf. 2017. “Composition, Respirable Fraction and Dissolution Rate of 24 Stone Wool MMVF with Their Binder.” *Particle and Fibre Toxicology* 14 (1): 29. https://doi.org/10.1186/s12989-017-0210-8.

Yang, Tao, Lizhu Hu, Xiaoman Xiong, Michal Petrů, Muhammad Tayyab Noman, Rajesh Mishra, and Jiří Militký. 2020. “Sound Absorption Properties of Natural Fibers: A Review.” *Sustainability* 12 (20): 8477. https://doi.org/10.3390/su12208477.