energies

Review

A Mini-Review on Straw Bale Construction

Ghadie Tlaiji [1], Pascal Biwole [1,2,*], Salah Ouldboukhitine [1] and Fabienne Pennec [1]

[1] Université Clermont Auvergne, Clermont Auvergne INP, CNRS, Institut Pascal, 63000 Clermont-Ferrand, France
[2] MINES Paris Tech, PSL Research University, PERSEE-Center for Processes, Renewable Energies and Energy Systems, 06904 Sophia Antipolis, France
* Correspondence: pascal.biwole@uca.fr

Abstract: Straw bale building construction is attracting a revived public interest because of its potential for reduced carbon footprint, hygrothermal comfort, and energy savings at an affordable price. The present paper aims to summarize the current knowledge on straw bale construction, using available data from academic, industry, and public agencies sources. The main findings on straw fibers, bales, walls, and buildings are presented. The literature shows a wide variability of results, which reflects the diversity of straw material and of straw construction techniques. It is found that the effective thermal conductivity, density, specific heat, and elastic modulus of straw bales used in construction are in the range 0.033–0.19 W/(m·K), 80–150 kg/m^3, 1075–2000 J/(kg·K), and 150–350 kPa respectively. Most straw-based multilayered walls comply with fire resistance regulations, and their U-value and sound reduction index range from 0.11 to 0.28 W/m^2 K and 42 to 53 dB respectively, depending on the wall layout. When compared to standard buildings, straw bale buildings do provide yearly reductions in carbon emissions and energy consumption. The reductions often match those obtained after applying energy-saving technologies in standard buildings. The paper ends by discussing the future research needed to foster the dissemination of straw bale construction.

Keywords: sustainable architecture; straw bale buildings; bio-based materials; thermophysical characterization; life cycle assessment

Citation: Tlaiji, G.; Biwole, P.; Ouldboukhitine, S.; Pennec, F. A Mini-Review on Straw Bale Construction. *Energies* **2022**, *15*, 7859. https://doi.org/10.3390/en15217859

Academic Editor: F. Pacheco Torgal

Received: 26 September 2022
Accepted: 21 October 2022
Published: 23 October 2022

1. Introduction

Buildings are responsible for 36% of the world's energy load and 37% of the CO$_2$ emissions [1]. The immense untapped potential for energy and carbon emission savings of the building sector makes it the prime player in energy transition and climate change mitigation. Global concern about environmental and energy issues has led many governments, worldwide, to issue new building regulations. In western countries, such regulations promote the use of low embodied energy and sustainable materials. For example, the 2020 French environmental regulation includes a new carbon requirement that must be met by all buildings constructed after 1 January 2022. Due to their affordability, low carbon footprint and interesting thermal, hygric and mechanical properties, bio-based materials are attracting a renewed interest from many academic researchers and private contractors. In this context, straw, as an agricultural waste product often produced close to the construction site, is increasingly considered and used as a construction material. Figure 1 shows the increasing number of academic and industry papers devoted to straw bale construction from 1990 to 2020. It should be noted that straw buildings appeared first in 1886 in the USA [2].

The present review aims at summarizing the current knowledge on straw bale construction. More detailed reviews can be found in [3–5]. This paper first presents the results of the thermophysical characterization of straw fibers and bales. It then discusses the hygrothermal and energy behavior of straw-based walls and buildings, along with their life cycle assessment. Last, the main open research questions regarding straw bale buildings are detailed.

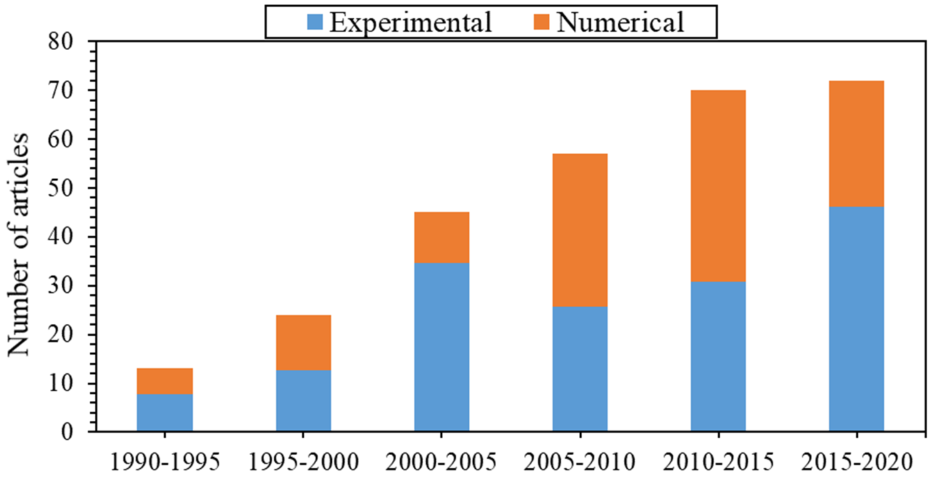


Figure 1. Experimental and numerical articles on straw bale construction between the years 1990 and 2020 [3].

2. Straw Fibers and Bales

Straw stalks are generally composed of three main parts: grain head, nodes, and internodes, as shown in Figure 2. Internodes are hollow tubular structures of a few millimeters in diameter, whose shell includes the epidermis, the parenchyma, and vascular bundles [6]. Researchers have mostly used digital microscopy and scanning electron microscopy (SEM) devices to get visual access to the internode and fiber microstructure [7–10]. They found that although the internode may be several centimeters long, the fibers located inside its shell are mostly 2 to 7 mm long, and pores are 2 µm to 100 µm large, depending on the straw type. Figure 3 shows the microstructure of a wheat straw internode, using digital microscopy and SEM analysis. Straw fibers are mainly composed of cellulose (40–80%), responsible for the thermal insulation property; lignin, (10–30%) responsible for the mechanical stability; moisture (6–8%); and ash (5–10%) [11–14].

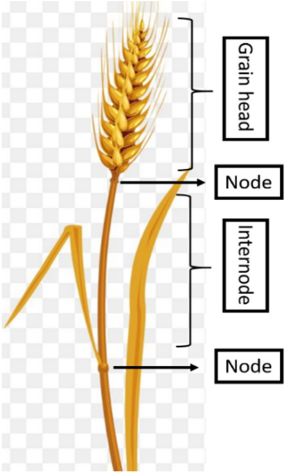
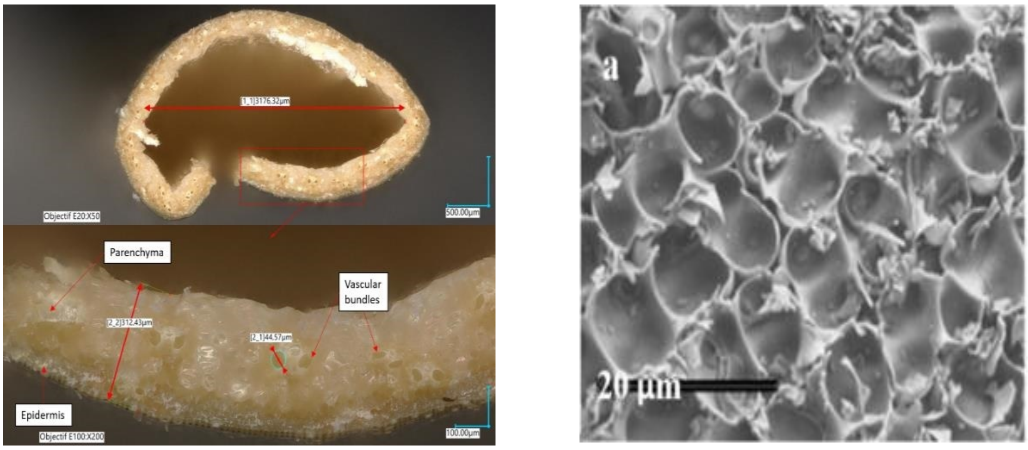


Figure 2. Different parts of a wheat stalk.

Straw bales are made of stacked and compressed straw stems. The bale's shape, dimension, and level of compression depend on the baler used. Rectangular bales used in building walls are usually from 60 to 130 cm high, 70 to 120 cm wide, and 50 to 280 cm long. Watts et al. [15] found that the density of barley straw bales ranges from 54.6 kg/m^3 to 78.3 kg/m^3, whereas that of oat and wheat straw bales ranges from 81 kg/m^3

to 106.3 kg/m^3. Many national building regulations impose a minimum bale density of 80 kg/m^3 for straw construction.



(**a**) (**b**)

Figure 3. (**a**) Transversal cross-section of an internode wheat straw using a digital microscope. (**b**) SEM analysis of a wheat straw shell [10].

Straw bales are classified as hygroscopic materials with moisture buffer values around 1.8 and capillary absorption of about 0.0155 kg/(m^2·s$^{1/2}$), due to their 90% porosity [16]. Several teams investigated the effect of straw type, fiber main orientation, bale density, average temperature, and relative humidity (RH), on the bale's effective thermal conductivity. The methodology was mainly experimental, using the hot guarded plate technique or flux meters to measure the thermal conductivity. It was found that the latter increases with increasing density, RH, and temperature, and decreases with higher cellulose content and when the fibers are predominantly oriented perpendicular to the heat flow. Increasing density reduces the amount of air trapped inside the bale, which explains the adverse effect on conductivity. High RH relates to the higher moisture content in the bale, which badly affects the conductivity because of the higher water conductivity. When the bale temperature rises, the number of molecules colliding increases due to the higher microscopic kinetic energy, thus increasing the thermal conductivity. Straw type relates to cellulose content and a reduced amount of lignin increases the thermally insulating porous microstructure. Last, when fibers are perpendicular to the heat flow, there is no solid conduction path through the bale, whereas in the parallel case, such paths are through the fibers, which are less insulant than air.

Table 1 presents research results on bale conductivity as a function of the mentioned parameters. The variability of the results reflects the diversity of the straw material, which depends on the straw type and production site. Therefore, bales from each site have specific thermophysical properties that should be measured before their use in construction. The thermal conductivity is always in the range [0.033–0.19 W/m·K] whereas the bale's density, temperature, and RH are in the range of 100–150 kg/m^3, −5 to 40 °C and 5–60% respectively, regardless of the fiber main orientation and straw type [17–20]. The thermal conductivity of a straw bale is lower than that of concrete (0.3–1.8 W/m·K), bricks (0.3–1.1 W/m·K), and wood (0.14–0.22 W/m·K) [21]. Straw bales' specific heat capacity varies from 1075 to 2000 J/(kg·K), with the measured value increasing with increasing bales' density and temperature [22,23]. Straw bales' heat capacity range is close to that of concrete, brick, and wood which is about 1000–2500 J/(kg·K) [24]. Regarding thermal effusivity and diffusivity, they are respectively in the range 417–775 J/(K·m^2·s$^{-1/2}$) and 0.1 × 10^{-6}–3.6 × 10^{-6} m^2/s, with the effusivity increasing with increasing bale density and the diffusivity displaying the inverse trend [19,22]. The thermal effusivity of concrete, brick, and wood are respectively 346–2000 J/(K·m^2·s$^{-1/2}$), 990–1161 J/(K·m^2·s$^{-1/2}$), and 23–255 J/(K·m^2·s$^{-1/2}$), whereas their diffusivity is respectively, 0.3× 10^{-6}– 0.7 × 10^{-6} m^2/s, 0.3 × 10^{-6} –0.4 × 10^{-6} m^2/s, and 0.2 × 10^{-6} –0.3 × 10^{-6} m^2/s [25]. Bales' hyric properties are seldom found in the literature. Most researchers measured the vapor diffusion resistance factor μ and found a value from 1.15 to 5, with μ increasing along with bale density [23,26–28]. This factor is very low compared to the μ-value of concrete which is 50–150, of brick which is 15, and of wood which is about 40 [29]. The difference between straw and other conventional materials is related to its porosity and cellulose content which improve their thermal properties.

Table 1. Straw bale thermal conductivity (λ), heat capacity (C_p) and thermal diffusivity (α) versus density (ρ), moisture content (MC) or relative humidity (RH), temperature (T), and the fiber's type and orientation.

Ref.	Fiber's Type	MC/RH (%)	T (°C)	ρ (kg/m^3)	Fiber's Orientation	λ (W/m·K)	C_p (J/kg·K)	α (m^2/s)
[18]	Wheat	MC 8.4	20	133	perpendicular	0.047	753.5	4.4×10^{-7}
					parallel	0.06		
	Rice			123	Random	0.08		
[30]	Rice	MC 11	23	107	perpendicular	0.0811	----	----
					parallel	0.1471		
[31]	Wheat	----	----	82–138	----	0.033	2000	3×10^{-7} -1.5×10^{-7}
	Barley		----	69–98		0.034	----	----
[32]	Barley	----	40	80	perpendicular	0.041	----	----
[33]	----	RH 50	23	77	----	0.066	----	----
[34]	Wheat	0	----	81–111	perpendicular	0.044	----	----
				105	parallel	0.067		
[20]	Barley	RH 50	10	60–120	parallel	0.0845–0.0875	----	----
				50–120	perpendicular	0.04–0.075		
	Barley chopped			35–80	random	0.039–0.045		
	Barley defibered			35–80	random	0.037–0.044		
[35]	Wheat	RH 50	----	63–123	random	0.059–0.064	----	----
		----	----	115		0.087		
[36]	Rice	MC 10–18	30	200–350	----	0.051–0.053	----	----
[37]	Wheat	MC 12.5	19	65.7	parallel	0.062	----	----
		MC 11.5		84.1		0.07		
[38]	----	RH 10	25	115	-----	0.094	----	----
[39]	----	RH 45	22	80	----	0.052	----	----
[40]	Wheat	MC 8	35	78	random	0.069	----	----
[23]	Rice	RH 0	0–40	80	random	----	1075–2025	----
			23			0.042	3847	
		RH 50	0–40	100		----	1075–2025	
			23			0.047	2970	
[22]	----	----	---	60	-------	0.067	600	18.2×10^{-7}
[19]	Rice	RH 40	30	68	random	0.06	----	2.4×10^{-7}
					perpendicular	0.057		
					parallel	0.15		
		RH 60			random	0.07		
					perpendicular	0.08		
					parallel	0.17		
		RH 80			random	0.07		
					perpendicular	0.075		
					parallel	0.19		

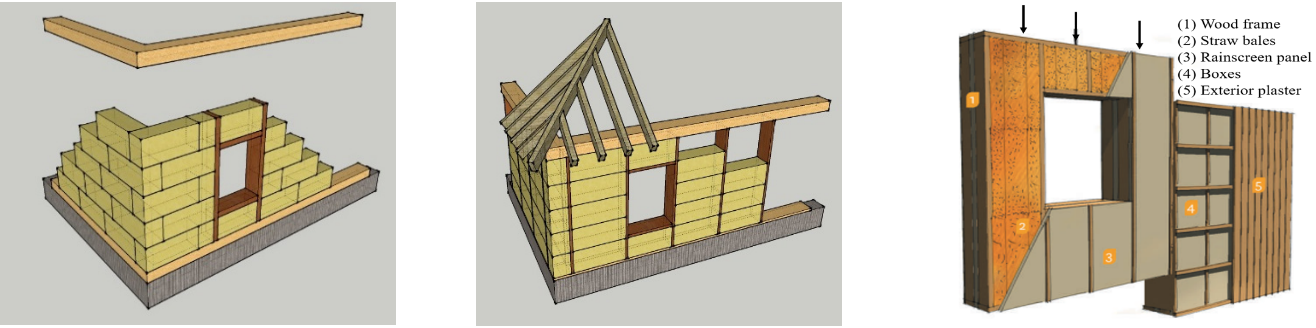
Regarding mechanical properties, Konečný et al. [41] and Ashour et al. [42] conducted tests on several types of straw bales by applying a 10 kN load. They got elastic modulus between 150 and 350 kPa for density values between 83 kg/m^3 and 100 kg/m^3 which is very low compared to those of concrete of about 10–30 GPa [43]. The deformation curves demonstrated the material's elastic behavior, with the bales almost fully recovering their initial shape after the release of the load.

3. Straw Walls and Buildings

Straw walls are generally made of a core straw bale layer within other outer finishing layers that may include plaster, cement, hardwood, an additional thermal insulation layer, and an unventilated gap. Depending on the wall structure and the materials' thickness, the resulting U-values mostly range from 0.11 [44] to 0.28 W/m^2 K [40], which is lower than that of building walls using conventional materials such as concrete or bricks. Several researchers [42,45–47] experimentally noted the ability of straw walls to reduce and time shift the variations of outdoor temperature and RH. Most found time lags and decrement factors of value 6–12 h and 0.01–0.08%, respectively [38,48]. Regarding the hygric properties, most studies agree on the very slow humidity absorption of straw walls [42,47,49]. This is mainly due to the high vapor diffusion resistance of the finishing layers and plasters. Degradation tests conducted on a straw wall at 28.5% RH showed no bacteria development [46,50]. Recently, Ghadie et al. [51] conducted a numerical study on different straw walls to find the best structure depending on the climate. They found that in terms of condensation risk and mold growth, straw walls with cement or wood covering best fit in tropical and temperate climates, coated straw walls with additional air layers in dry climates, and insulated straw walls are recommended in continental climates.

So far, most research on straw walls' fire resistance has used experimental methods. It was found that most structures could withstand fire temperature on one side above 1000 °C for two hours, thus complying with the international building code [52,53]. This is due to the limited amount of oxygen within bales of density above 80 kg/m^3 and to the fire resistance of the finishing layers such as plaster. Last, regarding acoustic performance, experiments showed that the sound reduction index of straw walls varies between 42 and 53 dB depending on the wall layout [39,54–56].

At the building scale, there are three predominant construction techniques for a straw building, as shown in Figure 4. In the loadbearing method [57–59], straw bales support the weight of the roof. The method's main limitations are the maximum area of openings, which should be less than 50% of the wall area and the height generally limited to a single story. The nonstructural (or infill) method [59–61] uses wood or reinforced concrete columns and beams to support the load. This technique allows high-rise buildings but requires more complex construction operations. Last, the prefabricated technique [62,63] allows assembling prefabricated wall panels on the construction site, thus reducing construction complexity and time.



(**a**) (**b**) (**c**)

Figure 4. (**a**) Load-bearing, (**b**) nonstructural, and (**c**) prefabricated straw building construction techniques (based on [28,59]).

The main goal of the use of straw is to reduce the building's energy consumption and carbon emissions. Chaussinand et al. [64] assessed a 300 m^2 straw load-bearing office building. They showed a final energy consumption of around 3800 kWh and primary annual energy of around 8.9 kWh/m^2 of floor area. Alcorn et al. [65] numerically assessed the life cycle of a straw bale and timber dwelling with a floor area of 200 m^2. They noted an annual energy consumption of 37.9 GJ whereas a standard house with conventional insulation, wood timber, and concrete floor consumes about 41.7 GJ per year. Compared with the standard house, they found a reduction of 1230 kg CO$_2$ equivalent per year that, interestingly, was almost the same as the total emission reduction from applying energy-minimizing technologies, excluding onsite renewable energy generation. Currently, one of the tallest straw buildings in the world is a seven-story apartment building including 15 residential units of 90 m^2 floor area each, located in St. Die des Vosges, France. The Jules Ferry building is labeled “passive house”, with a heating load lower than 15 kWh/m^2/year [66].

4. Conclusions

The existing literature represents an important step towards the dissemination of straw bale buildings. However, there are still several gaps in the existing knowledge. Measurements on bales’ hygric properties other than the vapor diffusion resistance factor are seldom found. The literature also lacks detailed models of the heat and mass transfer through straw fibers and bales, depending on the straw type, bale density, temperature, RH, and fiber orientation. Such models will help predict the hygrothermal and energy behavior of straw buildings. Similarly, the three main straw building construction methods have not been fully investigated in terms of their inherent benefits and limitations from the hygrothermal and mechanical perspectives. For example, it is still unclear which method delivers the highest thermal comfort, energy savings, and seismic resistance. Such studies should also include the building location and its scenarios of occupation and operation. Last, the role of straw as a regulator of indoor air moisture is still insufficiently documented, even though straw building contractors sometimes advertise this characteristic. Future studies should take into account the variability of the results, due to the changing nature of the thermo-physical properties of this bio-based material over time. Based on the energy results, the economic feasibility of straw buildings should be more intensively researched, especially in terms of payback period and life cycle cost. Those research steps are crucial to foster private and public interest in straw construction.

Author Contributions: Writing—original draft preparation, G.T.; writing—review and editing, P.B., S.O. and F.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IEA—International Energy Agency. 2021. Available online: https://www.iea.org/ (accessed on 13 October 2022).
2. SCM Lejeune, La Construction en Paille: Construire en Paille, Construire L’avenir, RFCP et SCM Lejeune. 2015. Available online: https://www.rfcp.fr/ (accessed on 1 September 2020).
3. Tlaiji, G.; Ouldboukhitine, S.; Pennec, F.; Biwole, P. Thermal and mechanical behavior of straw-based construction: A review. *Constr. Build. Mater.* **2022**, *316*, 125915. [CrossRef]
4. Cascone, S.; Rapisarda, R.; Cascone, D. Physical Properties of Straw Bales as a Construction Material: A Review. *Sustainability* **2019**, *11*, 3388. [CrossRef]
5. Koh, C.H.; Kraniotis, D. A review of material properties and performance of straw bale as building material. *Constr. Build. Mater.* **2020**, *259*, 120385. [CrossRef]
6. Ghaffar, S.H.; Fan, M. Revealing the morphology and chemical distribution of nodes in wheat straw. *Biomass Bioenergy* **2015**, *77*, 123–134. [CrossRef]
7. Laborel-Préneron, A.; Magniont, C.; Aubert, J.-E. Characterization of Barley Straw, Hemp Shiv and Corn Cob as Resources for Bioaggregate Based Building Materials. *Waste Biomass Valorization* **2018**, *9*, 1095–1112. [CrossRef]
8. Bouasker, M.; Belayachi, N.; Hoxha, D.; Al-Mukhtar, M. Physical Characterization of Natural Straw Fibers as Aggregates for Construction Materials Applications. *Materials* **2014**, *7*, 3034–3048. [CrossRef]
9. Kurniati, A.; Darmokoesoemo, H.; Puspaningsih, N.N.T. Scanning Electron Microscope Analysis of Rice Straw Degradation by a Treatment with α-L-arabinofuranosidase. *Procedia Chem.* **2016**, *18*, 63–68. [CrossRef]
10. Halvarsson, S.; Edlund, H.; Norgren, M. Wheat Straw As Raw Material for Manufacture of Straw (Mdf). *Bioresources* **2010**, *5*, 1215–1231.
11. Alpha Cellulose–CAMEO. 2016. Available online: http://cameo.mfa.org/wiki/Alpha_cellulose (accessed on 10 February 2021).
12. Wang, D. Basic Lignin Chemistry. Available online: https://pdf4pro.com/view/basic-lignin-chemistry-59bdf9.html (accessed on 13 October 2020).
13. Plazonić, I.; Barbarić-Mikočević, Z.; Antonović, A. Chemical Composition of Straw as an Alternative Material to Wood Raw Material in Fibre Isolation. *Drv. Ind.* **2016**, *67*, 119–125. [CrossRef]
14. Comité National des Coproduits ADEME, Co-Produits Riches en Ligno-Cellulose, Paille de Céréale, Fiche 1. Available online: https://librairie.ademe.fr/ (accessed on 12 November 2020).

15. Watts, K.C.; Wilkie, K.I.; Tompson, K.; Corson, J. Thermal and mechanical properties of straw bales as they relate to a straw house. In Proceedings of the agricultural institute of Canada Annual conference, Ottawa, ON, Canada, 9–12 July 1995; Agricultural Institute of Canada: Ottawa, ON, Canada, 1995; pp. 95–209.
16. Wihan, J. *Humidity in Straw Bale Walls and its Effect on the Decomposition of Straw*; University of East London School of Computing and Technology: London, UK, 2007.
17. JCostes, J.-P.; Evrard, A.; Biot, B.; Keutgen, G.; Daras, A.; Dubois, S.; Lebeau, F.; Courard, L. Thermal Conductivity of Straw Bales: Full Size Measurements Considering the Direction of the Heat Flow. *Buildings* **2017**, *7*, 11. [CrossRef]
18. McCabe, J. The Thermal Resistivity of Straw Bale Construction. Master's Thesis, The University of Arizona, Tucson, AZ, USA, 1993.
19. Sabapathy, K.; Gedupudi, S. Straw bale based constructions: Measurement of effective thermal transport properties. *Constr. Build. Mater.* **2019**, *198*, 182–194. [CrossRef]
20. JVėjelienė, J. Processed straw as effective thermal insulation for building envelope constructions. *Eng. Struct. Technol.* **2012**, *4*, 96–103.
21. Solids, Liquids and Gases–Thermal Conductivities. Available online: https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html (accessed on 13 October 2022).
22. Goodhew, S.; Griffiths, R. Sustainable earth walls to meet the building regulations. *Energy Build.* **2005**, *37*, 451–459. [CrossRef]
23. Marques, B.; Tadeu, A.; Almeida, J.; António, J.; de Brito, J. Characterisation of sustainable building walls made from rice straw bales. *J. Build. Eng.* **2019**, *28*, 101041. [CrossRef]
24. Solids–Specific Heats. Available online: https://www.engineeringtoolbox.com/specific-heat-solids-d_154.html (accessed on 13 October 2022).
25. Module 48: Simple Thermal Analysis for Buildings—CIBSE Journal. Available online: https://www.cibsejournal.com/cpd/modules/2013-01/ (accessed on 13 October 2022).
26. Labat, M.; Magniont, C.; Oudhof, N.; Aubert, J.-E. From the experimental characterization of the hygrothermal properties of straw-clay mixtures to the numerical assessment of their buffering potential. *Build. Environ.* **2016**, *97*, 69–81. [CrossRef]
27. Liuzzi, S.; Rubino, C.; Martellotta, F.; Stefanizzi, P.; Casavola, C.; Pappalettera, G. Characterization of biomass-based materials for building applications: The case of straw and olive tree waste. *Ind. Crop. Prod.* **2020**, *147*, 112229. [CrossRef]
28. RFCP. Réseau Français de la Construction Paille | RFCP. Available online: https://www.rfcp.fr/ (accessed on 22 February 2022).
29. *LBN 002-01*; Instruments Regulatory Codes and Standards, Regulations Regarding Latvian Construction Standard. Thermotechnics of Building Envelopes: Riga, Latvia, 2002.
30. California Energy Commisio. *CEC/ATI, Thermal Performance (ATI-20227)*; California Energy Commisio: Fresno, CA, USA, 1997.
31. Ashour, T. The use of renewable agricultural by-products as building materials. *Work* **2003**, *2*, 013-2467034.
32. Beck, A.; Heinemann, U.; Reidinger, M.; Fricke, J. Thermal Transport in Straw Insulation. *J. Therm. Envel. Build. Sci.* **2004**, *27*, 227–234. [CrossRef]
33. Grelat, A. Utilisation de la Paille en Parois de Maisons Individuelles a Ossature Bois, Centre D'Expertise du Batiment et des Travaux Public 2004. Available online: https://amper.ped.muni.cz/~{}jhollan/letters/straw/pdfBwxFwYWDVG.pdf (accessed on 22 February 2022).
34. FASBA. *Thermal Performance: Strawbale Building, Research Development 2003–2009*; FASBA: Norwalk, NY, USA, 2009.
35. Shea, A.; Wall, K.; Walker, P. Evaluation of the thermal performance of an innovative prefabricated natural plant fibre building system. *Build. Serv. Eng. Res. Technol.* **2013**, *34*, 369–380. [CrossRef]
36. Wei, K.; Lv, C.; Chen, M.; Zhou, X.; Dai, Z.; Shen, D. Development and performance evaluation of a new thermal insulation material from rice straw using high frequency hot-pressing. *Energy Build.* **2015**, *87*, 116–122. [CrossRef]
37. Conti, L.; Barbari, M.; Monti, M. Steady-State Thermal Properties of Rectangular Straw-Bales (RSB) for Building. *Buildings* **2016**, *6*, 44. [CrossRef]
38. Gallegos-Ortega, R.; Magaña-Guzmán, T.; Reyes-López, J.A.; Romero-Hernández, M.S. Thermal behavior of a straw bale building from data obtained in situ: A case in Northwestern México. *Build. Environ.* **2017**, *124*, 336–341. [CrossRef]
39. D'Alessandro, F.; Bianchi, F.; Baldinelli, G.; Rotili, A.; Schiavoni, S. Straw bale constructions: Laboratory, in field and numerical assessment of energy and environmental performance. *J. Build. Eng.* **2017**, *11*, 56–68. [CrossRef]
40. Cascone, S.; Evola, G.; Gagliano, A.; Sciuto, G.; Parisi, C.B. Laboratory and in-situ measurements for thermal and acoustic performance of straw bales. *Sustainability* **2019**, *11*, 5592. [CrossRef]
41. Konečný, P.; Teslík, J.; Hamala, M. Mechanical and Physical Properties of Straw Bales. *Adv. Mat. Res.* **2013**, *649*, 250–253. [CrossRef]
42. Ashour, T.; Georg, H.; Wu, W. Performance of straw bale wall: A case of study. *Energy Build.* **2011**, *43*, 1960–1967. [CrossRef]
43. What Is the Modulus of Elasticity of Concrete? 9 Important Points. Available online: https://www.gcelab.com/blog/what-is-the-modulus-of-elasticity-of-concrete (accessed on 13 October 2022).
44. Barbara. *Information Guide to Straw Bale Building, for Self Builders and the Construction Industry*; Amazon Nails: Todmorden, UK, 2001.
45. Mesa, A.; Arenghi, A. Hygrothermal behaviour of straw bale walls: Experimental tests and numerical analyses. *Sustain. Build.* **2019**, *4*, 10. [CrossRef]
46. Thomson, A.; Walker, P. Condition monitoring and durability assessment of straw bale construction. In *Contribution of Sustainable Building to Meet EU 20-20-20 Targets, Design for Life Cycle and Reuse, Portugal*; Braganca, L., Pinheiro, M., Mateus, R., Eds.; Elsevier: Guimaraes, Portugal, 2013; pp. 791–798.

47. Robinson, J.; Aoun, H.K.; Davison, M. Determining Moisture Levels in Straw Bale Construction. *Procedia Eng.* **2017**, *171*, 1526–1534. [CrossRef]
48. ODouzane, O.; Promis, G.; Roucoult, J.-M.; Le, A.-D.T.; Langlet, T. Hygrothermal performance of a straw bale building: In situ and laboratory investigations. *J. Build. Eng.* **2016**, *8*, 91–98. [CrossRef]
49. Sabapathy, K.A.; Gedupudi, S. In situ thermal characterization of rice straw envelope of an outdoor test room. *J. Build. Eng.* **2020**, *33*, 101416. [CrossRef]
50. Thomson, A.; Walker, P. Durability characteristics of straw bales in building envelopes. *Constr. Build. Mater.* **2014**, *68*, 135–141. [CrossRef]
51. Tlaiji, G.; Pennec, F.; Ouldboukhitine, S.; Ibrahim, M.; Biwole, P. Hygrothermal performance of multilayer straw walls in different climates. *Constr. Build. Mater.* **2022**, *326*, 126873. [CrossRef]
52. Džidić, S. Fire resistance of the straw bale walls. In Proceedings of the 5th International Conference, Contemporary Achievements in Civil Engineering, Subotica, Serbia, 21 April 2017.
53. Theis, B. Straw Bale Fire Safety a review of testing and experience. In *Ecological Building Network (EBNet)*; The Taunton Press: Newtown, NS, USA, 2003.
54. Dalmeijer, R. Straw-bale Sound Isolation and Acoustics. *Last Straw–Int. J. Straw Bale Nat. Build.* **2006**, *53*. Available online: https://thelaststraw.org/strawbale-sound-isolation-acoustics/ (accessed on 20 October 2022).
55. Trabelsi, A.; Kammoun, Z. Experimental evaluation of acoustic characteristics of straw walls. *Can. Acoust.* **2018**, *46*, 49–56.
56. Wall, K.; Walker, P.; Gross, C.; White, C.; Mander, T. Development and testing of a prototype straw bale house. *Proc. Inst. Civ. Eng. Constr. Mater.* **2012**, *165*, 377–384. [CrossRef]
57. CD2E Accelerateur de L'Eco-transition, Construction en Bottes de Paille: Performance Technique, Economique et Ecologique. Available online: https://cd2e.com/ (accessed on 9 September 2022).
58. Ashour, T.; Wu, W. Using barley straw as building material. In *Barley: Production, Cultivation and Uses*; Elfson, S., Ed.; Nova Science Publishers, Inc.: Hauppauge, NY, USA, 2011.
59. Techniques—A Travel in the Straw-Bale Buildings in Turkey. Available online: https://samanbalya.wordpress.com/building-techniques/ (accessed on 18 October 2021).
60. Aznabaev, A.A.; Ovsyannikova, A.V.; Povzun, A.O.; Gaevskaya, Z.A. Assessment of straw construction technologies in terms of thermal efficiency of enclosing structures. *Constr. Unique Build. Struct.* **2016**, *43*, 104–116.
61. Arnaud, L.; la Rosa, C.; Sallet, F. Mechanical behaviour of straw construction following the GREB technique. In Proceedings of the 11th International Conference on Non-Conventional Materials and Technologies (NOCMAT), Bath, UK, 6–9 September 2009; pp. 1–8.
62. Egis-Straw: The Ultimate Green Building Solution? Available online: https://www.egis-group.com/all-insights/straw-the-ultimate-green-building-solution (accessed on 9 September 2022).
63. Building with EcoCocon Straw Panels | EcoCocon. Available online: https://ecococon.eu/se/blog/2020/building-with-ecococon-panels (accessed on 9 September 2022).
64. Chaussinand, A.; Scartezzini, J.L.; Nik, V. Straw bale: A waste from agriculture, a new construction material for sustainable buildings. *Energy Procedia* **2015**, *78*, 297–302. [CrossRef]
65. Alcorn, A.; Donn, M. Life cycle potential of strawbale and timber for carbon sequestration in house construction. In Proceedings of the 2nd International Conference on Sustainable Construction Materials and Technologies, Ancona, Italy, 28–30 June 2010; pp. 885–895.
66. European Straw Building Association. 7-Storey Modular Building in St. Die des Vosges. Available online: https://strawbuilding.eu/7-storey-modular-building-in-st-die-des-vosges/ (accessed on 18 October 2022).