Towards the low-cost housing through using recycled materials as an exterior thermal insulation

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Abstract. Recycled materials had recently been reintroduced into the research of sustainable materials to combat climate change. this type of Insulating materials for the envelope is mainly characterized by their favorable thermal properties. This research aims to examine the thermal properties and energy performance of dry straw and pulp construction insulation boards, which are local products specific for the arid and semi-arid region of Algeria. The research methodology consists of two parts: the first is experimental, based on a fabrication of insulating plates and tested using thermal conductivity. the second part expresses a series of energy simulations of buildings via TRNSYS and Design Builder software. Subsequently, the thermal performance of the envelope with straw insulation plates was compared to conventional recycled wall filling materials such as hollow wood fiber brick and Cellular concrete r through simulations of the energy consumption of an existing residential building in Bechar. They were generated by keeping the thickness of the climate wall and U-value constant. the results show that straw has a better result, reducing energy consumption and maintaining comfort. Straw insulated plates reduced heating and cooling needs in the home. They increased by 25% and 16%, respectively. Their energy efficiency was higher than the performance of other materials even if the walls in the scenario have the same U-value as Straw walls in current and future weather conditions.

Keywords: instruments, insulation, thermal conductivity, energy consumption

1 Introduction

The global building sector currently consumes nearly 40% of the total energy produced. In Iraq, the residential building sector by itself consumes 48% of the total energy generated, and 69% of this portion is used for cooling and heating [1,2].
The building energy-saving potential is significantly affected by the thermal-mass and insulation of the building envelope, which can save energy portion ranging from 32%

through to 58% and up to 85% with achieving delays peak of energy demand in the late evening [3-4]
The efficiency of thermal insulation using natural materials in enhancing sustainability, particularly in hot dry areas, is a significant area of study. Natural insulation materials, derived from renewable resources, offer numerous advantages over conventional insulation options, especially in terms of environmental impact and thermal performance.

Benefits of Natural Insulation in Hot Dry Areas were very interesting to improve thermal indoor comfort and energy performance.

- Natural materials like straw and wood fibres help regulate indoor temperatures by absorbing heat during the day and releasing it at night, which is particularly beneficial in hot climates. [AI, 2024]
- Environmental Impact: The production of natural insulation materials typically involves lower energy consumption compared to synthetic options. For instance, the cultivation of hemp and straw requires less energy and contributes positively to carbon sequestration.
- Health and Safety: Natural insulations are generally non-toxic and improve indoor air quality by managing moisture levels, which can prevent old growth and enhance occupant health.
- Durability and Maintenance: Many natural insulation materials exhibit high durability and require less maintenance over time, leading to long-term energy savings and reduced environmental impact during their lifecycle.
- Cost-Effectiveness: Although the initial costs of natural insulation may be higher, their long-term benefits, including energy savings and lower environmental impact, can make them more cost-effective over time. [Artificial intelligent, 2024]

2. A literature reviews

Several recent literature reviews have examined the use of natural materials for thermal insulation in buildings:

D. BOZSAKY his work presents the natural thermal insulation materials into rediscovered materials like cork, wood wool, and fiberboard, as well as recently developed materials from agricultural waste and by-products. (D. BOZSAKY, 2019)

Almusaed et al. note a novel approach by introducing plant panels as an integral component in future building designs, epitomizing the next generation of sustainable structures and enhances buildings' indoor environments. this innovative solution seeks to provide a sustainable alternative by addressing the challenges of unsustainable practices, outdated standards, limited implementation of new technologies, and excessive administrative barriers in the construction industry. The obtained outcomes will provide stakeholders within the building sector with pertinent data concerning performance and durability. Furthermore, these results will enable producers to acquire essential information, facilitating product improvement.

The research of Mahrous et al. emphasizes the capacity of recycled plastic to act as a cost-efficient substitute for thermal insulation. This substitution to boost the insulation of building envelopes, preserve energy, and enhance thermal comfort, boost increase the insulation of building envelopes, preserve maintain energy, and enhance thermal comfort, especially in hot developing countries. The results may provide valuable is for future investigations and advancements in sustainable construction materials, facilitating the shift towards a circular economic model. (Mahrous et al.2024)

In this research, we are using Natural insulation materials as a Straw and wood fibers, which can be categorized into several types, including:
Straw: Straw bales have been used historically for construction. They are a by-product of grain harvests, acting as a carbon sink and providing good sound insulation. Straw's properties make it suitable for hot, dry climates where thermal mass can help regulate indoor temperatures.
Wood Fiber: Timber-based insulation materials, such as wood fiber boards, offer excellent thermal insulation, reducing heat gain in summer and heat loss in winter. They are also vapor-permeable, which helps manage moisture within building structures.

Hence, biomass-based insulation materials were recognized as eco-friendly and long-lasting insulating materials that are a component of France's transition to limited emission carbon and positive-energy of buildings. To better fit into the concept of circular economy, an article by Rabat et al., 2022 highlights these biomaterials' end of life in order to prevent burial. The research explores the waste management strategies, with a focus on waste-to-energy, that show the most promise. (benoudjafer et al., 2023)
Superti, V., and al., (2021) Producers of (recycled) thermal IMs in Switzerland and abroad. IMs can either be entirely produced from virgin raw materials, or both virgin raw materials and recycled materials. IM waste to be recycled can either be directly imported from abroad or generated within Switzerland, during the production stage itself (i.e., at the producer’s site), during the installation phase at the construction site, or during the recycling phase that follows building renovation/deconstruction or that occurs at the end of life of IM products (e.g., EPS, stonewool, etc.). IM waste can be either issued from the C&D sector or other sectors. IMs produced can either be exported outside Switzerland, as input to make other products or to be distributed and installed in buildings.[2] (Superti, V., and al., 2021) [17]

With simulation, in hot arid region, the vertical greening system can reduce indoor air temperatures by 2.3 ◦C, improving comfort. Green roofs, walls, and all techniques lowered the temperature by 1.87 ◦C, 1.79 ◦C, and 1.90 ◦C, respectively [benoudjafer et al., 2022]

With Experimental test [22] Thermal insulation and its significance in building energy consumption in Hot climate as a Coconut fiber, as thermal insulators, reduced interior air temperature by 2.8–3.1 ◦C.

Using natural materials for thermal insulation in hot dry areas not only enhances sustainability through reduced energy use and lower carbon footprints but also improves the overall living conditions by providing better thermal regulation and air

quality. The integration of materials like hemp, straw, and wood fibres represents a viable strategy for sustainable building practices in these climates

Thermal insulation properties of baled straw is one of the most investigated properties of this material, which is consequently to be baled straw commonly used as a filler in the construction of walls and roofs. One of the numerous studies of the thermal insulation properties of straw bales was done in France in laboratory conditions and results were compared with the results measured at a real object in which the straw was used as a filler in the wall structure.[16]. One of many studies on the thermal insulation properties of straw bales was carried out in France under laboratory conditions, compared to results measured on a real object in which the straw was used as filler in the wall structure .[17]

Among these studies, Drochytka et al. [11] examined the possibility of recovering polyester fibers (textile waste) in the implementation of thermal insulation materials to eliminate the amount of waste going to landfills. Different types of samples were prepared by mixing waste polyester fibers with binders of different dosages. The results obtained showed that the thermal properties of the samples depend on the bulk density and the temperature. this new insulation has a high resistance to humidity and biotic attack, non-toxic, manufacturing process free of chemical binders and glue.

In addition, the study by Dissanayake et al. [12] studies the recycling of post-industrial textile waste, in particular Nylon/Spandex (NS) and Polyurethane (PU). The compression molding method was used to produce three-layer samples sandwiched in an NS/PU/NS sequence. The best thermal insulation property was obtained for the composition (%W) 60:40, NS:PU corresponding to a thermal conductivity of 0.0953 W/(m.K).

The study by Patnaik et al. [13] have developed thermal and acoustic insulation from waste wool and recycled polyester fibers for applications in the building industry. Different types of samples were studied: two-layer material 50% used wool and 50% recycled polyester fibres, 100% used wool and 100% recycled polyester fibres. they found that a two-ply material offered the best properties.

The study by Bessa et al. [14] evaluated the application potential of chicken feather fibers to reinforce polymers (epoxy resins). The composite materials were produced using a compression molding process. The results obtained showed that the thermal resistance of the composite materials depends on the rate of chicken feather fibers, with an increase of about 37% on the thermal resistance, between the samples with ratios of 60:40 and 80:20 of chicken feather fiber and epoxy resin, respectively, was recorded. For a ratio of 80:20, a value of 0.175 m2 K·W-1 was achieved. These results can be explained by the morphological characteristics of the chicken feather, which has a hollow structure which contributes favorably to these properties.

The paper present by Siti Nur Aishah Mohd Noor, 2019 presents the production of four types of recycle materials to be made as thermal insulation products namely as cardboard, newspaper, eggs tray and waste paper. Then, the recycled cellulose thermal

insulation will be tested in phase of density, water absorption and thermal properties. According to the experiment result, it showed that newspaper is the most suitable material as main component of recycle cellulose fibre for thermal insulation followed by waste paper. In conclusion, the best recycled cellulose for thermal insulation at wall is newspaper and suitable to be as an alternative for thermal insulation improvement in future. [20]

2 Materials and methods

This study addresses inquiries concerning energy efficiency, practical implementation, and the bioeconomic aspect of future green building concepts.
Thermal insulation for the building envelope were made by straw material and Ordinary Cement. Our plan is to investigate a brand-new type of thermal insulation that is fastened to the exterior walls of pre-existing homes and is made of fibrous materials and fabrics.
For this experimental endeavor, recycled wood fibers are used as the insulating material. The suggested exterior insulation method employs plates created by combining common binders with insulation made from recycled "wood fiber." (Benoudjafer et al. 2023)

A total of three samples of thermal insulation based on nature and recycling were made using different binders: white cement and lime putty reinforcement. (Table 1).

Table 1. Hydrothermal properties of natural unconventional insulation materials [4]

	Density kg/m3	**Thermal conductivity**	**Specific heat**	**Fire classification**	**Water vapor diffusion**
Sheep wool	10-25	0.038-0.054	1.3-1.7	B2-B1	1.0-3.0
Straw bale	**80-120**	**0.052-0.08**	**-**	**B**	**1-2**
fibers wool	110-240	0.038-0.049	-	E	3-5

Insulation boards made from recycled materials are characterized by better thermal resistance compared to conventional products (expanded polystyrene) (table 1).
The insulation efficacy of recycled textiles, in contrast, is comparable to that of lightweight synthetic materials like straw bale and fibers wools due to their low thermal

conductivity and low density. Low thermal conductivity values and high density are characteristics of straw bale.

Table 2. Thermal features of thermal insulation used in thermal [13],[14]

	Compositions	**The thick-ness of layer (m)**	**Total thickness**	**U (W/m2.K)**	**Description**
Initial	Outside plaster cement brick blade of air cement brick concrete plaster	0,015 0,10 0.02 0.10 0.015	0.25	0.89	Sample apartment multi zone located in Bechar, 75 m2
ETI with recy-cled Materials Wood fiber 4x (500X500 mm2)	Outside plaster cement brick blade of air insulated plates with **WOOD FIBRES** Finishing coating [18]	0.015 0.02 0.25 0.08 0.05	0.32	0.53	installation and fixing of insulation plates with a finishing coat on an out-side wall [17]
ETI with recy-cled Materials Wood fiber 4x (500X500 mm2)	Outside plaster cement brick blade of air insulated plates with **STRAW** Finishing coating [18]	0.015 0.02 0.25 0.08 0.05	0.32	0.53	installation and fixing of insulation plates with a finishing coat on an out-side wall [17]

As seen in Table 2, millwork upholstery had wood fibres. These fibres were separated, cleaned to get rid of contaminants, and then manually gathered. A significant amount of waste from the production of wood is represented by wood fibres. Jute bags that had previously been used for storage and transportation were repurposed to gather straw, which was then utilized to prepare samples.

Figure 1: Insulation laying phases

2.2. **Presentation of the studied building and its instrumentation**

The building studied is an existing house, built the city of Béchar (arid and semi-arid climatic zone). The building is 150 meters long, 12 meters wide, has 1 floor for a total of 12 meters in height. Its main facades are oriented to the North-West and South-East (Figure 1). The initial envelope of the building is composed of a wall in uninsulated 15 cm concrete blocks and single tilting glazing.

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Figure 2. Presentation of the interior and exterior building examined

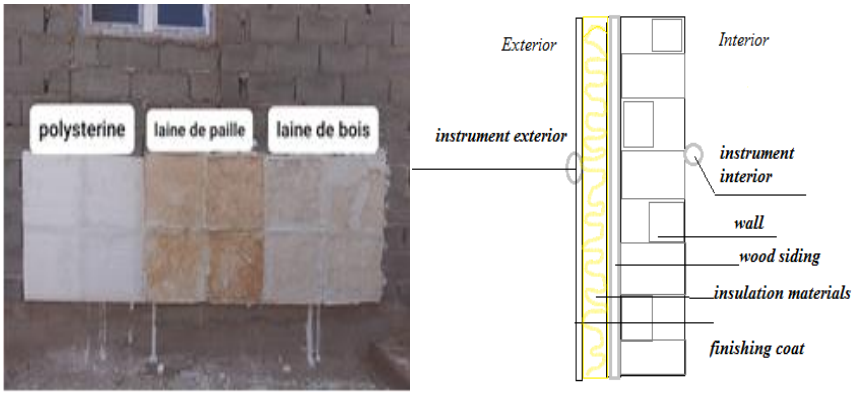

Figure 3. Presentation of the insulation thermal exterior examined

3 Results and discussions

3.1. Indoor comfort analysis

Most importantly, the energy benchmark must be established with little available information to achieve generalization that can be applied to most buildings [28,29].

The result of indoor comfort analysis shows that the building with insulation can reduce ait temperature for 2C° in the summer, with straw or wood fibers.

Table 03: **Indoor comfort analysis with IPS *of different components***

	T° Initial	T ° insulated with STRAW	T° Insulated with fiber wood
Tmax	37.75	30.94	32.68
ATMax		6.88	4.14
TMoyenne	33.94	30.85	30.81
ATmoyenne	-	2.09	2.13
Tcomfort	26	26	26
IPS	-	0.30	0.30

3.2. Evaluative Q cooling and Q heating

The superior performance of the façade in terms of energy consumption of heating and cooling reduction is due to the material used to insulating based on recycled materials. The building with insulation can reduce energy 56% than initial building.

Table 4. Evaluation of indicators of the energy performance of strategies sustainable

System Indicator

System/ Indices	Initial building	Fiber's wood	Straw
Q heating (KWh /m^2)	100	40	40.25
Q cooling (KWh /m^2)	60	30	33.6
Cep (KWh /m2)	160	70	73
Saving Energy %	-	56.25	54.56

With:

-Bbiobât. (Bbiobât= 2Bheating + B cooling + 5 lighting)

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-Cep= Cep heating + Cep -cooling+ Cep –lighting+ CepECS + Cep-auxs+ Cep-auxv (Cep auxs= cep auxv=0 et cep éclairage= 4.5 KWh/m2 et cepECS= 45.5KWh/m2

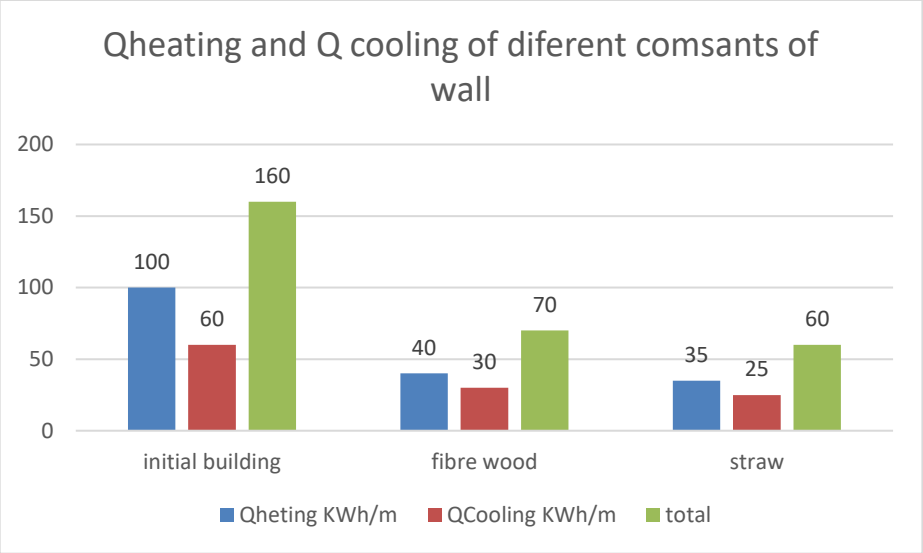

Figure 4. consumption energy of one month of building with thermal insulation based on recycled materials

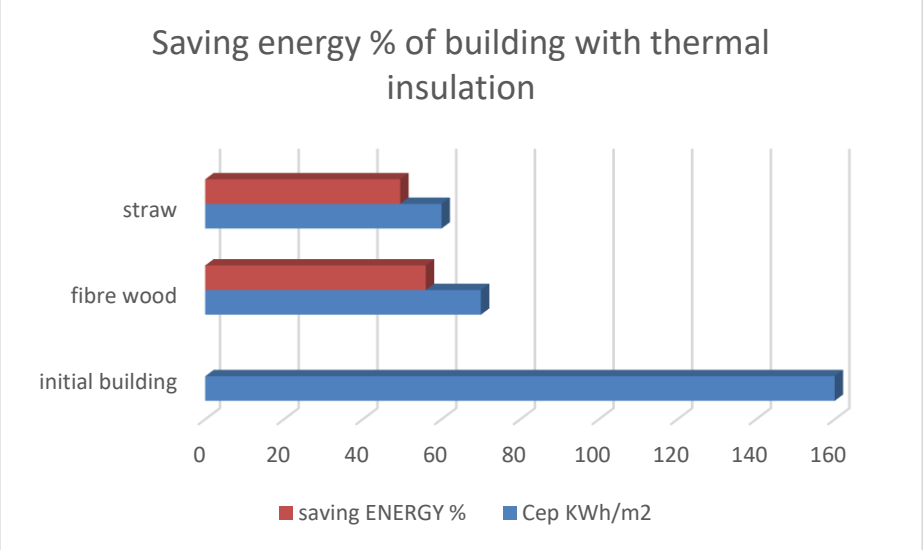

Figure 5. Evaluative energy saving % of different components of thermal insulation using straw and wood fibers

It is estimated that adequate thermal insulation reduces heating and cooling costs by up to 56% and 54.56, with using fiber's wood and straw. The cost of investment in insulating materials is recouped in up to 5 years, through reduced bills and even in reduced capacities of heating and cooling systems. If we consider the stock of existing buildings and the new ones to be built, we can measure the energy savings for a country or for the world.

4 Conclusion

In this research, recycling materials for thermal insulation in hot, dry environments are investigated experimentally and with simulation. This article lists the types of insulators, their uses, how they are produced and installed, their compositions, their pricing, as well as their present and projected volumes. A high priority was given to the treatment scenarios for fibrous materials since it is anticipated that a large amount of fiber wood insulation will be produced in this area through the recycling and composting of some bio-based goods. In the technical-economic analysis, it is also examined how these tactics are limited by technical and financial issues.
At last, to complete the theoretical background and on the other hand, the experimental work of a built facade, an economic and technical analysis of energy innovation operations will be conducted in light of this research work. A brief Conclusions section, which may be included as a stand-alone section or as a subsection of a Discussion or Results and Discussion section, may convey the study's key conclusions. Conclusions ought to include an overview of significant discoveries and their consequences for the topic of research that defines the article's form. This research should, in the future, be focused on examining the technological viability of various thermal insulation of external walls on various families of recycled materials or biomass-based insulation materials by conducting laboratory tests and upscaling. It is necessary to appreciate condition optimization for each material (temperature, residence duration, carrier gas, and pressure). Following that, it is needed to estimate the market values of various items in order to compare the best option in light of each case study's unique requirements.
Regarding the environmental and financial advantages of exterior insulation, it is important to consider local policies, the climate, and the geographical features of arid regions.

5 Declaration of competing interest

The authors state that they have no known competing financial interests or personal ties that could have seemed to affect the work reported in this study.

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