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Energy Efficiency Coupled with Lightweight Bricks: Towards Sustainable Building: A review

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Abstract: This study investigates energy use in the construction sector and the potential for reducing energy consumption by improving the thermal efficiency of various building components, including walls, windows, roofs, and floors. The evaluation included a discussion on the prospects of reducing energy use. The building envelope is one of the most important factors to consider in terms of the heating and cooling energy efficiency of buildings. Walls are the fundamental component of a building's envelope and should provide thermal and acoustic comfort without compromising the aesthetic features of the building. The walls have a heat transfer area that is substantially higher than average, and the amount of heat gained or lost depends on the temperatures of the wall's inner and outside surface areas. Therefore, walls have a vital role in reducing the energy consumption of buildings. Bricks are a necessary component of high-performance thermal insulation, and lightweight bricks are especially useful in this regard. Bricks that are specifically manufactured for use in wall construction play an essential role in the management of energy consumption. The study has, as a result, provided a synopsis of the production of lightweight bricks in accordance with the source of the raw materials (e.g. Agriculture and industrial waste, etc).

Keywords: Lightweight brick, Thermal conductivity, Energy efficiency in buildings.

Contents

Name	Abbreviation
Organization for Economic Co-operation and Development	OECD
World energy outlook	WEO
United Nations Environment Program	(UNEP)
European Union	EU
World green building council	WGBC
Leadership in Energy and Environmental Design	LEED
Greenhouse Gases	GHG
Extruded polystyrene	EPS
Heating, Ventilation, and Air Conditioning	HVAC
Department of Energy	DOE
European Energy Performance of Buildings	EPBD
Gigatonne carbon dioxide	GtCO2
International energy agency	IEA
Lead glass sludge	(LGS)
Magnesia	(MgO)
Lead	Pb

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Iron (III) oxide	Fe2O3
Calcium Carbonate	CaCO3
ASTM International - Standards Worldwide	ASTM
Indian standards	IS
Megapascal	MPa
Weight percentage	wt%
Toxicity characteristic leaching procedure	TCLP
Recycled paper mill residue	RPMR
Rice husk ash	RHA
Deinking paper mill sludge	DPMS
Calcium Oxide	CaO
Potato peel powder	PPP
Sour orange leaf	SOL
Olive pruning	OP
Olive leaves	OL
Olive wood	OW
Sugarcane bagasse ash	SBA
Silicon dioxide	SiO2
High-density polyethylene	HDPE
Polyethylene terephthalate	PET
Polyethylene terephthalate plastic	PETP
Grain size	Δ
Carbon dioxide	CO2
Nitrous oxide	NOx
Sodium aluminosilicate hydrate gel	(N-A-S-H)
Silicate	SiO4
Oxidoperoxy(oxo)alumina	AlO4
Molar	M
Sodium Hydroxide	NaOH

1. Introduction: Energy consumption challenges

As a result of problems with energy use in the construction industry and significant population growth, energy consumption has increased dramatically in recent years [1-3] (**Fig.1**). Approximately 200,000 people are born every day [4], which has necessitated the construction and establishment of new cities and increased the amount of electricity required [5].

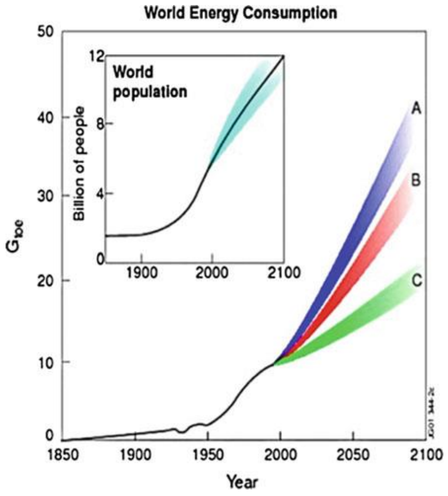

Figure 1. World energy consumption in the past 150 years. Figure reprinted with permission from Ref. [6]. Copyright belongs to Springer.

According to the World Bank, the annual consumption of electricity will increase as incomes and standards of living improve (**Fig.2**) [7]. Based on projections made by the WEO, the total amount of electricity will rise from 20.1 trillion kWh in 2010 to 35.2 trillion kWh in 2035[8].

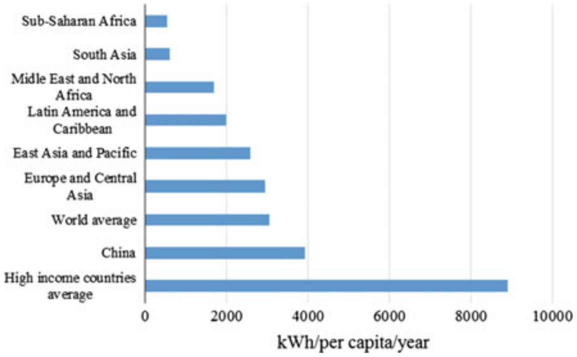

Figure 2. Annual electricity consumption per capita. Figure reprinted with permission from Ref. [6]. Copyright belongs to Springer.

Consumption of energy is mostly driven by the construction industry. About 39% of the US overall primary energy consumption goes toward powering structures [9]. According to a study that was conducted in 2007, buildings are responsible for between 30 and 40% of the world's principal energy sources [10]. According to the findings of a research that was recently compiled by the IEA, the amount of energy that was used in buildings rose by 8.5% between the years of 2010 and 2018 [10-12]. **Table 1** shows the changes in OECD countries' energy usage [10-12].

Table 1. Total yearly energy usage among OECD nations [10, 12].

Year	Mega tons of oil equivalent	Year	Mega tons of oil equivalent
1975	810	2000	1125
1980	850	2005	1200
1985	904	2010	1235
1990	943	2015	1163
1995	1051	2018	1196

The thermal comfort and air quality of interior areas may be significantly improved by using a sizeable fraction of the building's total energy consumption. The remaining portion of energy consumption is used for a variety of purposes, including the generation of electricity, the heating of water, and the operation of various home appliances [10, 13]. Research has indicated that building cooling demand increased globally by 33% between 2010 and 2018 [10]. Subsequently, fuel combustion increased in order to generate more electricity [14-16]. Accordingly, emissions account for a sizable proportion of GHG (e.g., carbon dioxide, methane, and nitrous oxide) [6]. Evidence of this environmental disaster may be seen in the form of rising sea levels, ocean acidification, heavy rain, heat waves, severe atmospheric events, ecosystem degradation, species extinction, health issues, and infrastructure damage [17].

The increasing use of energy contributes to the warming of the planet and leads to the depletion of energy supplies. The first quarter of the twenty-first century has seen significant rises in global energy usage. According to the IEA, the increase in global energy consumption between 1971 and 2014 reached approximately 93% [10, 18]. The largest part of this increase is attributed to buildings, and as stated by the UNEP, 40% of global energy consumption is from the building sector [19]. Reportedly, buildings in Europe are responsible for more than 30% of the continent's total GHG. According to some sources, commercial buildings spend the majority of their energy budget on heating, cooling, and lighting [20]. Consequently, the reduction of energy consumption relies on the productive use of energy [6, 10, 21].

Technological advancements mean the comfort conditions offered to building occupants also play a crucial role in the building sector’s energy consumption [6, 10, 22]. In this context, buildings draw attention in terms of lessening their total energy usage and mitigating the amount of GHG they emit [23]. The European Union (EU) has developed strategies to improve the energy efficiency of buildings, and member states have made great progress toward meeting their Kyoto Agreement commitments via the implementation of related rules [24].

Overcoming the climatic change caused by GHG emissions from the energy sector requires significant efforts [6]. In many instances, the use of energy-saving methods may dramatically cut the amount of energy that is consumed in buildings. Recent years have seen an increase in both the price of energy and environmental concerns, which has led to a resurgence in interest in the pursuit of more energy-efficient construction techniques. The potential and the need for increased energy efficiency in buildings have been recognized by governments and scientific groups all over the globe, and significant efforts have been undertaken in this area [16, 21]. Currently, the World Green Building Council (WGBC) has 82 nations that have taken up green building initiatives.

LEED, which is a globally recognized green building certification system, acknowledges that energy efficiency is an essential quality of green buildings [16, 21]. The concept of environmentally friendly, or "green," buildings takes into account a wide range of concerns, such as the conservation of resources (such as energy, water, land, and materials), reduction of pollution in the natural environment, and improvement of the quality of both the indoor and outdoor environments [16].

2. Energy Efficiency in Buildings

The building sector includes residential, commercial, institutional, and public buildings that consume high amounts of energy, with the expectation being that global demand for buildings will continue to grow [21]. There are many different kinds of structures, such as workplaces, medical facilities, educational institutions, public safety facilities, places of worship, storage facilities, hotels, public libraries, and retail centers, among many more [21]. Global heating and cooling demands are expected to rise by 79% in residential buildings and 84% in commercial buildings between 2010 and 2050 [25]. Studies have shown that commercial buildings consume more than half of their total energy supply for heating and lighting, despite the fact that various business operations have distinct energy requirements (Fig.3) [21].

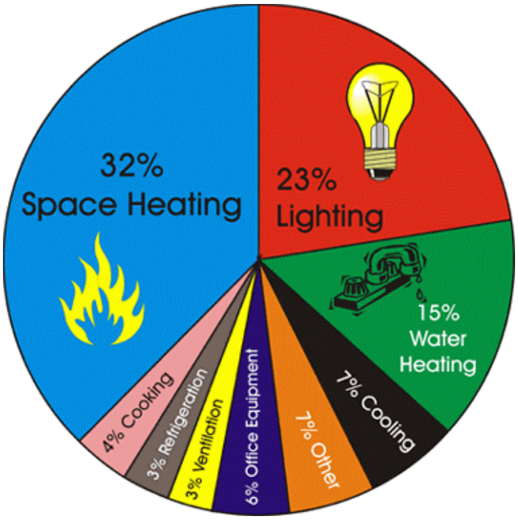

Figure 3. Energy use in commercial buildings [21].

Electricity and natural gas are the two forms of fuel that are most often used in commercial buildings. On occasion, commercial buildings may employ a different energy source, such as locally produced group or district energy, in order to provide either heating or electricity to the facility (**Fig.4**) [21].

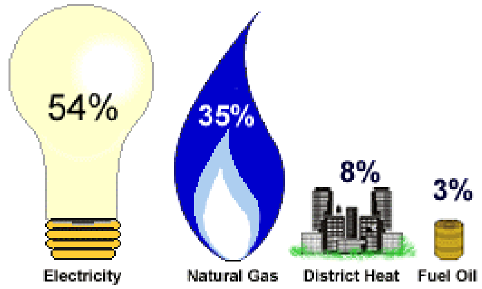

Figure 4. Percentage breakdown of energy usage [21].

That's why the production of GHG is the single most wasteful, polluting, and energy-intensive human endeavor ever [22]. The lodging industry is responsible for a significant portion of these environmental consequences [22]. In most cases, lodging establishments use methods in their design and services that need a lot of resources like electricity and water, as well as disposable items [26-29]. Typically, efficient resource usage from the building design to the end-users is low [22]. Minimizing building energy involves solutions that focus energy efficiency and passive renewable energy, including building design, components, heating, cooling, illuminating, and utilities [6, 21]. Reducing these environmental impacts requires sound decision-making during the building design phase [6, 22], with the goal of enhancing the buildings' energy performance [6, 22].

There might be a large decrease in building energy use if structures are planned properly [30-32]. Furthermore, lower energy use reduces GHG and lessens operational costs [22]. Thus, energy efficiency measures play a crucial role in reducing the building sector's GHG emissions. According to estimates [6, 33, 34], energy efficiency in relation to buildings' heating and cooling needs prompted a decrease of between 2 and 3.2 $GtCO_2$ per year by 2020. Other estimates have mentioned a potential reduction of approximately 5.4–6.7 $GtCO_2$ per year by 2030 [6, 35]. Achieving such reductions requires prioritizing building codes associated with high energy performance [6].

3. Investigating Energy Efficiency in Buildings

Implementing active or passive energy-efficient strategies can improve building energy consumption [16]. Improvements to Heating, Ventilation, and Air Conditioning (HVAC), electrical lighting, and other such systems are examples of active methods, while alterations to the components of the building envelope are examples of passive techniques [26, 28, 31, 36, 37]. As a result of developments over the last few years, there has been a resurgence of interest in energy efficiency initiatives that are friendly to the environment and are meant to alleviate worries over environmental pollution and the energy problem [16]. The quality of the internal environment and its ability to exert control over it are determined by the building envelope, which is impervious to changes in the weather and other external factors [6, 16]. An important aspect of a passively designed building envelope is the reduced energy needed to maintain a comfortable inside temperature [6, 16, 21]. This method takes into account the heat gain from the outside, which is affected by the building's walls, fenestration, roof [38], foundation, thermal insulation[26, 27], thermal mass[39], and external shading systems[40-42], into consideration [16, 43]. Regardless of the ever-changing weather outside, this crucial aspect is what ultimately decides the quality of the structure and what governs the internal conditions [16, 21, 43, 44]. Building envelopes interact with air, water, temperature, light, and sound while adhering to architectural aesthetics, economic constraints, and low energy consumption [43, 45-47]. Better thermal performance improves a building's energy efficiency as it ages [46]. The amount of energy that is transferred between the interior and outdoor environments is determined by the thermal properties of the walls and roofing [46].

Several researchers have examined the relationship between enhancements to the building envelope and the structure's overall energy use [6, 16]. Studies recorded energy savings of 31.4% and peak load savings of 36.8% from the base case for high-rise apartments in the hot and humid climate of Hong Kong thanks to passive energy efficient strategies [16]. These savings were compared to the base case and were a result of a reduction in peak load. EPS thermal insulation in walls, whitewashing external walls, employing reflective coated glass window glazing, 1.5 meter overhangs, and connecting wing walls to all windows are some of the methods that are included in these plans [16, 48]. Using the building energy modelling tool developed by the Department of Energy (DOE), further study evaluated the thermal and heat transfer performance of a building envelope in the subtropical climatic conditions of Hong Kong [16]. Building envelope designs that were more efficient with energy saved 35% and 47% of total and peak cooling requirements, respectively [16, 49].

Building envelope code standards have undergone substantial revisions over the course of time, resulting in improvements that continue to be shown at higher performance levels [16]. The changes that have been made to the building envelope requirements in the UK are shown in Table 2 [16]. Each modification has resulted in significant improvements to the requirements for the building envelope, placing further emphasis on the rising need of energy saving.

Table 2. Code standard U-values (in Wm^{-2}K^{-1}) for UK buildings[16].

Envelope element	1995 standard U-values (Wm^{-2}K^{-1})	2000 standard U-values (Wm^{-2}K^{-1})	Percentage reduction in U-value (%)
Walls	0.45	0.35	22
Roofs	0.25	0.16	36
Floors	0.45	0.25	44
Windows	3.3	2.2	44

There has been great progress made in the investigation of innovative and environmentally friendly materials for use in the construction of building envelopes. Sustainable earth materials including unfired clay bricks, a straw-clay combination, and straw bales were studied for use in the building of new earth walls or the upgrading of existing earth walls [50]. The thermal transmittance of these structures should be less than 0.35Wm^{-2}K^{-1} in order to be in compliance with the building rules in the UK [16]. A well designed building envelope may dramatically decrease energy use via day lighting, reduced HVAC loads, and other means [16]. To drastically cut energy costs while simultaneously increasing efficiency, new building exterior materials and technologies are required [51].

The "low" performance levels of thermal insulators are a significant barrier to the energy efficiency of buildings [6]. The continuous growth in the thickness of thermal insulation materials may be attributed to the pressing need of lowering the energy consumption of buildings [6]. For instance, the amount of insulation that is used in northern Europe has almost doubled in thickness (Fig.5). Because of this constraint, there will be substantial monetary and technological repercussions. A high thickness reduces the amount of usable interior space that is available in existing structures and drives up the cost of insulation. As a consequence of this, the production of high-performance thermal insulator materials (with low thickness) has evolved into a technological and scientific difficulty that continues to warrant new research.

The constraints of the EPBD framework, which result in a lack of chances to minimize energy consumption, are yet another significant problem with the present state of the building materials and energy efficiency. When placed in such a scenario, the use of construction materials that contain less embodied energy becomes a top concern [6]. One strategy includes optimizing the materials that make up the building envelope in order to lower the room temperature, so maintaining an acceptable level of thermal comfort within the structure, while at the same time decreasing the amount of energy that is used for air conditioning [52, 53]. This technique is consistent with the theory that the conductivity of building materials (in addition to convection and radiation) has a considerable impact on the rate at which heat is transferred, in particular through the walls of the structure.

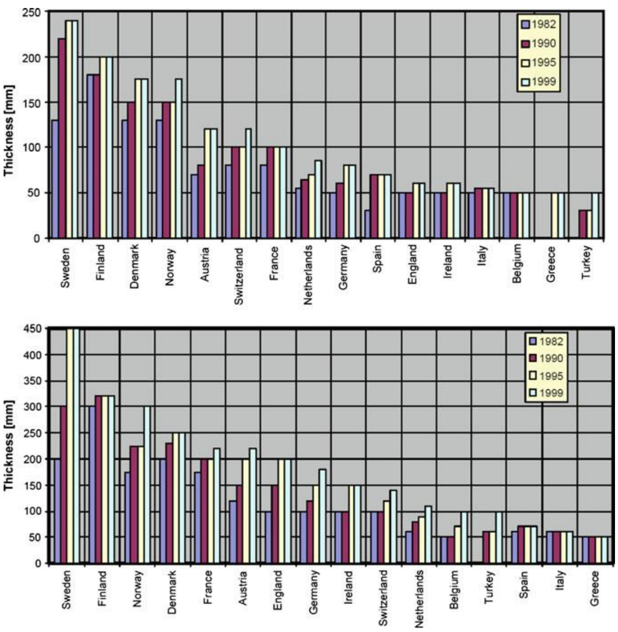

Figure 5. Evolution of thermal insulation thicknesses in several European countries: above in walls and below in roofs. Figure reprinted with permission from Ref. [6]. Copyright belongs to Springer.

According to the findings of a research conducted by Faggal, increasing the wall thickness and adding additional thermal insulation both enhance the interior thermal performance and reduce the amount of energy required for heating and cooling [53]. Mishra et al. [54], conducted research comparing the amount of energy saved in a mud home to that of a brick building. According to the findings he obtained, the optimal insulation thickness is somewhere in the range of 5.2 to 7.4 cm. The amount of energy that may be saved per square meter of a structure varies depending on the kind of building wall insulation used, the climate, and the cost of fuel [54].

Another research found that using a phase change material, such as polyethylene glycol-E600, as a wall material within the building significantly reduced the amount of heat that entered the room, leading to an increase in energy efficiency of 33% [55]. Mishra [54] demonstrated that using mud slurry as an insulation material saved energy by up to 45%, and that using straw as insulation for a roof was able to achieve a 13% reduction in heating load. These findings were based on an investigation into how much energy could be saved in a mud house in comparison to a brick structure. [56]. Despite the fact that ash blocks are three times more expensive than clay bricks, Kumar et al. [57], proved that the embodied energy of the former is equal to 57% less than that of the latter. In addition, when compared with a construction made of brick walls, the total amount of energy that an ash block building consumes over the course of 20 years is reduced by 33,863 kWh. An eco-brick that was created by combining fly ash and debris from building and demolition as a composite material had an embodied energy figure that was 16.8 % lower than that of fly ash bricks [58, 59].

According to the findings of a research that was carried out by Shaik and Kumar, the time lag and decrement factor of composite construction materials was much larger than that of their homogeneous counterparts [60]. The temperature differential and decrement factor for a two-storied building in Chennai, Tamil Nadu, India were investigated by using the simulation program to fly ash and ordinary bricks. The study was carried out in India. During the warmest months of April, May, and June, the highest interior air temperature recorded for was on average 3 to 4 °C lower than the temperature observed for ordinary bricks [61].

4. The influence of exterior walls on energy efficiency and thermal comfort.

According to some estimates, the need for cooling in buildings will rise [62]. By the end of the century, cooling loads might increase by anywhere from 50 % to more than 90 %, depending on the climatic zone [63]. According to the IEA (2013) [6, 8], by the year 2050, worldwide energy consumption for cooling would skyrocket by about 150%, while energy consumption for cooling in emerging countries will climb by 300% to 600%. The impact of ambient cooling on worldwide energy consumption amounted to 4% in 2010, and the global growth in ambient cooling reached roughly 60% between the years 2000 and 2010 [64].

There have been a number of studies that have concentrated on various components of buildings, such as walls, windows, roofs, and floors, in an effort to enhance thermal efficiency [65]. When it comes to the energy efficiency of buildings in terms of both heating and cooling, the building envelope is one of the most important factors to consider. It is possible to disassemble building envelopes into their primary components, which include the outer walls, floors, roofs, ceilings, windows, and doors (Fig. 6) [10]. he extremely variable amount of energy lost through a building's envelope is dependent on a wide variety of variables, including the age and type of the structure, the climate, the construction method, the orientation of the building, the geographic location, and the behavior of the occupants[51]. Figure 7 is an illustration of the physical model that depicts the building description and wall design.

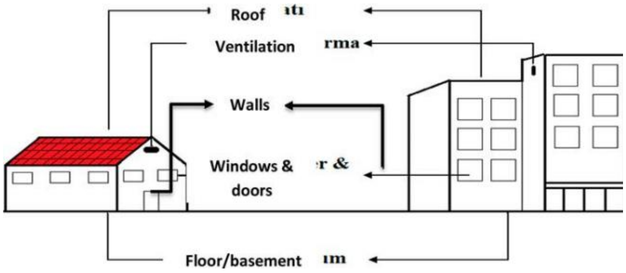

Figure 6. Building envelope components [10].

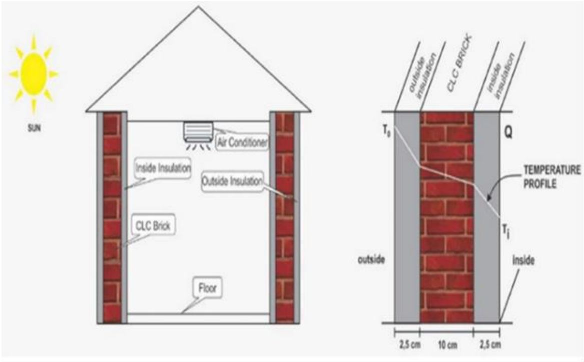

Figure 7. Building description and wall design [66, 67].

In order to minimize down on the amount of energy that is used by buildings, it is necessary to do research on low-carbon building materials, enhance building envelopes, look to nature for answers, optimize equipment, and improve efficiency systems. The modification to the building exterior will result in a reduction in the amount of energy that is needed for heating and cooling the building [10]. The total amount of money invested into improving the energy efficiency of buildings throughout the globe reached US$140 billion in 2017, representing a 3% increase when compared to the amount invested the year before. A little less than half of the investments are made in non-residential structures, which are responsible for one-quarter of the total floor area of buildings throughout the nation (Table 3). According to the figures, 49% of the overall investment goes toward improving the buildings' exteriors [10].

Table 3. Global expenditures on energy-efficient construction [10].

	Residential	Non-residential
Building envelope	$43.4 billion	$23.8 billion
Ventilation	$14 billion	$25.2 billion
Household appliances	$8.4 billion	$5.6 billion
Lighting	$5.6 billion	$14 billion
Total	$71.4 billion	$68.6 billion

Walls, which make up the majority of a building's envelope, are responsible for providing thermal and acoustic comfort and should do so without sacrificing any aesthetic considerations[16]. The thermal resistance (R-value) of the wall demonstrates its significance since it has an effect on the amount of energy that is used, particularly in tall structures that have a high ratio between the wall and the total envelope area[16].

The impact of thermal insulation is accounted for in the center-of-cavity R-values and clear wall R-values that are now available on the market [68]. Materials used for walls are the most important component in determining the level of thermal insulation. Walls are traditionally categorized as either being wood-based, metal-based, or masonry-based, depending on the materials that were used in their construction [16].

The use of many other cutting-edge building wall designs contributes to the enhancement of both energy efficiency and comfort. The great bulk of efforts made to increase the energy efficiency of buildings are concentrated on the building's outside structures[69]. A technique of this kind demonstrates its significance due to the fact that it enhances the thermal performance of the building envelope and lowers the amount of energy that is used [62]. Both heat loss and heat gain may be affected by a building's walls, which are part of the building's envelope.

Walls are responsible for roughly one-third of the heat loss that occurs in uninsulated brick dwellings (Fig. 8) [66, 67]. Researchers are interested in the wall design because it has the potential to increase the thermal resistance of buildings. Studies have shown that there are three approaches that may limit the amount of heat transferred through a wall: creating new model walls, manufacturing wall materials with unique properties, and optimizing the combinations of elements used in wall construction [70].

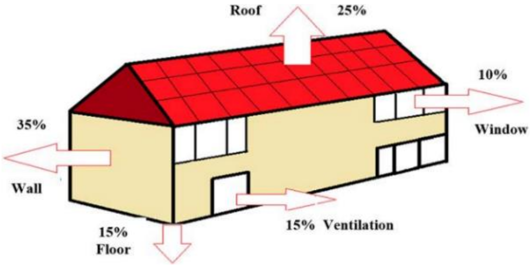

Figure 8. Rates of heat loss through the building [10].

5. Light-weight bricks

High-performance thermal insulation relies heavily on bricks. Bricks that are specifically manufactured for use in wall construction play an essential part in the management of energy consumption [16]. In addition, bricks are often utilized in the process of constructing the walls of residential and commercial structures [10]. The walls have a heat transfer area that is substantially higher than average, and the heat gains and losses are dependent on the temperatures of the wall's inner and outside surface areas [71]. Therefore, walls play a significant role in the process of minimizing the amount of energy used in buildings [10]. In recent years, it has been widespread procedure to use glass material to fill the spaces that are present in the building's outside shell [6, 10]. The newer designs put an emphasis on the functionality of the structures as well as the comfort of the people living in them [10, 43]. This method enhances the aesthetics of the building's outside, as well as its internal look, the comfort of the surrounding environment (both visually and thermally), and the efficiency of the building's energy use [72]. However, the research reveals that glass has a poor thermal resistance in comparison to hollow block, which is a building material that is utilized for the construction of walls. The U-value of the glasses ranges from 3.3 to 0.5 watt-meters per °C, depending on the qualities of the glasses. The overall U-value of the window may range anywhere from $4Wm^{-2}K^{-1}$ to $0.7Wm^{-2}K^{-1}$ when the joinery and glass are taken into consideration[10, 72]. This new information suggests that the thermal performance of the wall is dependent on the bricks that are used in the construction. Because clay and concrete are used in the production of the bricks, the thermal characteristics of the bricks will be influenced by the raw materials [10, 72, 73]. Bricks made from fired ceramic are the earliest known example of an artificial construction material. The ancient Egyptians were the first to make use of bricks as a construction material; however, cultures in Mesopotamia and ancient Rome also made use of them. Bricks have experienced a variety of transformations, many of which have helped to maintain and even improve the beneficial attributes that they originally had [10].

Bricks are chemically inert, yet they nonetheless serve a purpose because of properties such strong mechanical resistivity, water vapor permeability, thermal insulation, and heat accumulation [74]. Bricks also have a high-water vapor permeability rate. The interior environment and the structures' energy use are both impacted by these factors. Because of these factors, brick makers need to develop items made of bricks that greatly cut down on the amount of energy needed. One method for increasing the efficiency with which buildings use energy is to considerably improve the thermal performance of the parts that make up the structure. Bricks used as construction components have an effect on both the loss and uptake of heat [10]. Lightweight bricks, in contrast to their more traditional counterparts, have the potential to reduce overall energy consumption and improve thermal comfort.

5.1. Definitions and properties of light-weight bricks

There is no uniform description of lightweight blocks. They instead include a broad range of structural components that are lightweight, have low compressive strength, are very porous, and have low thermal conductivity. Bricks may be prepared in one of two ways: either by heating them in a kiln to temperatures of up to a thousand degrees Celsius, or by using a cold technique involving chemical processes. When flammable components are added to the raw mixture or when pores are created that generate a gaseous phase, both have a high porosity [75].

5.2. Methods for firing lightweight bricks

These bricks are built using the same methods as traditional clay bricks. A visual representation of the procedure is shown in **Figure 9**.

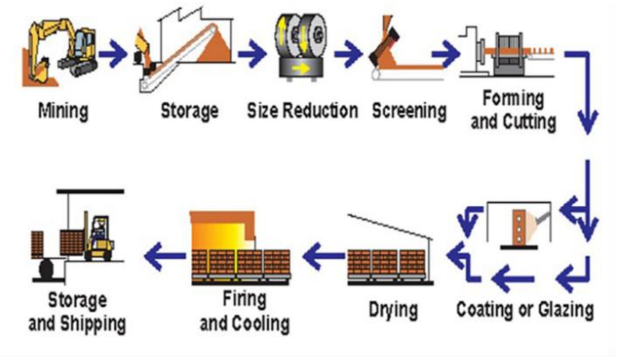

Figure 9. Producing clay bricks entails a number of stages [76].

We may outline these procedures as follows [76]:

- Mined raw materials are crushed and kept in the facility either in sheds divided by vertical walls or outside in conical heaps. These materials typically consist of clay and sand.
- The following phase involves utilizing impact or attrition mills to reduce the particle size of the raw materials. Oversize is returned to the incoming feed after screening the output fractions. Bricks are typically formed by first combining the dry mix with water (15%-30% by weight), and then either extruding or, less often, pressing the mixture into shape. Adding flammable substances is the next phase. The length of mud coming out of the extruder is slashed to the appropriate lengths.
- The wet bricks are next dried to temperatures between 80 and 100 °C in batch or continuous dryers.
- The last process, fire, gives the bricks their final, solidified shape. This step is performed in batch kilns or shuttle types for low outputs, whereas continuous kilns of the tunnel type are used for high outputs.

Batch or tunnel kilns are the most common kind of kilns used for firing clay bricks. In terms of output, shuttle kilns are ideal for producing lightweight bricks at low productivity, whereas tunnel kilns are optimal for producing huge quantities of lightweight bricks continuously. For times varying from 10 hours to 40 hours, the furnace is set between 800 and 900 °C. Bricks that have only been partially vitrified due to over firing may be a nightmare to place. A tunnel kiln is seen in Figure 10. The bricks are set on cars, and then the cars are rotated in and out of the kiln at regular intervals [76].

Figure 10. Tunnel kiln for firing bricks**.**

5.3. Types of combustible materials used to produce lightweight bricks porous

Because of their ability to oxidize or disintegrate at low temperatures in the kiln, several elements, especially organic waste, are mixed in water with the primary raw materials (clay and sand) to create voids (300 °C – 500 °C). The most prevalent materials include the following:

5.3.1. Lightweight bricks-based fuel waste

Porous structures in clay bricks have been produced using oily wastes from the oil and gas sector, reducing the bulk density and heat conductivity of the bricks. As a result of their high calorific value, such residues allow the firing temperature to be lowered to safer levels [77, 78]. The formation of glassy phases in these leftovers makes the manufactured bricks unusable owing to their poor adherence to cementing layers [79].

5.3.2. Lightweight bricks-based sludge

Dumping wastewater treatment sludge in landfills or estuaries has serious negative effects on the ecosystem. Poor sludge management might have monetary repercussions because of a lack of valorization legislation or investment [80]. This problem might be solved by using recovered sludge from wastewater treatment plants into eco-friendly, lightweight earth bricks. Incorporating various sludge wastes into clay bricks is possible. Wastewater sludge is combined with clay and water at a concentration of up to 40%, and then fired at a temperature of 1080 °C. There was an increase in firing shrinkage and water absorption when sludge was included [81].

Several authors have attempted adding sewage sludge to clay bricks [82-84]. Researchers found that the more sludge they added, the more porous the material became. Basegio et al. [84], exploited tannery byproducts that included clay at concentrations of up to 30% by weight. The temperature during the fire reached 1000 °C. The researchers found that when sludge concentration rose, porosity rose with it, and water absorption rose with it. When heated to 1100 °C, the material's bulk density and mechanical strength both increased. Paper sludge had similar outcomes when combined with clay [85]. Houssame et al. [80], replaced clay earth material with different wastewater treatment plant sludge percentages (0, 1, 3, 7, 15, and 20 wt%) to fabricate bricks. The prepared mixtures are molded (160mm x 40mm x 40mm) and pressed at 6.5 MPa. The brick samples undergo preparation in an oven drier between 20 °C and 50 °C, the process of which saves energy. Table 4 summarizes the mechanical, physicochemical, and thermal properties of unfired fabricated sample bricks. The porosity increased with a rise in the sludge percentage while the bulk density decreased. The sludge contains a high amount of humic acid, which has the opposite charge to clay. Thus, clay produces flocculants on earth particles by a process of absorption of humic acid. Since the humic acids and clay interact, the resulting aggregate has interparticle linkages that create void space. When the sludge percentage is increased, the compressive strength and thermal conductivity decrease.

Adding more sludge increases the silica particles, which are dominant in clay and sludge, in the clay-like structure and creates open pores, which, in turn, decreases the sand particles' friction, mechanical properties, and thermal conductivity [86, 87]. Bricks that have been assigned to the earth Bricks Class 3 category are suitable for use in real-world applications as non-load-bearing and walling constructions. Hamdy et al. [88], investigated the possibility of stabilizing LGS with reactive magnesium oxide via the process of fabricating lightweight construction bricks. The thermal treatment of magnesium carbonate at temperatures of 800 and 1200 °C results in the development of two distinct types of magnesium oxide, designated respectively as MgO-800 and MgO-1200. The LGS and MgO are mixed together in a variety of weight ratios (75–25, 50–50, and 25–75 wt. %). Dry mixtures of LGS–MgO were mixed for 30 minutes. The next phase involved water addition mixtures mixed at 180rpm and then transferred to stainless steel molds (228mm in length, 64mm in height, and 114mm). The samples were cured at 23 °C for different curing periods (1, 7, 30, 90, and 180 days). The bulk density values of the hardened samples decreased, and the MgO-800 content increased from 1.26gcm^{-3} to 1.06gcm^{-3} depending on the MgO-800 content.

However, MgO-1200 usage increased the bulk density of the produced bricks at all ratios from 1.55gcm^{-3} to 1.7gcm^{-3} due to the exposure of MgO to high temperatures increasing their specific gravity and affecting the bulk density. For all samples, the compressive strength gradually increased up to 180 days. When compared to LGS-MgO-1200, LGS-MgO-800 had the maximum compressive strength at all compositions. When compared to LGS-MgO-800 (50-50) (13.05 MPa) and LGS-MgO-800 (25-75) (8.10 MPa), LGS-MgO-800 (75-25) had the maximum compressive strength (29.07 MPa) after curing for 180 days. Because of this change, water uptake was shown to be greater for LGS-MgO-800 (75-25), LGS-MgO-800 (50-50), and LGS-MgO-800 (75-25), with values of 15.16, 17.00, and 17.35, respectively. For the most part, this finding was consistent with (the ASTM C62 limit). All LGS-MgO-800 mixes achieved an immobilization degree between 95.88 and 99.85% after just one day of hydration, with Pb concentrations below the acceptable TCLP level in every case. After one to 180 days of curing, LGS-MgO-1200 combinations bucked the trend by showing Pb contents greater than the toxicity characteristic leaching procedure limit. Increasing the proportion of MgO to LGS in any given LGS-MgO combination increases the Pb immobilization rate. These changes in results suggest that the curing time, MgO reactivity, and MgO concentration are the primary characteristics that greatly impact the Pb immobilization rate.

It was investigated by Lingling, X. et al. [89, 90], how different amounts of glass waste powder affected the performance of bricks. Their research indicated that the bricks' endurance was improved because of the diminished alkaline reaction caused by the glasses' modest size (less than 75mm). In addition, the compressive strength of bricks made with 15% or 30% glass waste dropped, whereas the water absorption and porosity of bricks made with more than 30% glass waste improved. Bricks should be manufactured at a temperature of about 1100 °C, as indicated by the harmonic structure. Bricks made from water treatment sludge and rice husk ash had more water absorption than traditional bricks, according to research by Yousif et al. [91]. Adding rice husk ash to the bricks made them stronger and more durable. Jelly made by mixing rice husk ash and water was shown to have a significant effect on the durability of bricks. For instance, the compressive strength of bricks fired at a temperature lower than 1200 °C and containing 75% rice husk ash was much higher than that of regular bricks. The unit weight of bricks made with rice husk ash was less than that of standard bricks.

Table 4. Effect of sludge in the properties of clay.

Brick samples	Porosity (%)	Bulk density (g/cm^3)	Capillary Water absorption coefficient (g/cm^2.min0.5)	Compressive strength (MPa)	Specific heat capacity (KJ/Kg.K)	Thermal conductivity (W/m.K)
Reference Clay	1.04	1.77	25.10	6.17	0.63	0.51
Reference Clay + sludge 1%	2.90	1.75	28.75	6.02	0.66	0.48
Reference Clay + sludge 3%	5.04	1.72	31.17	5.75	0.71	0.42
Reference Clay + sludge 7%	7.00	1.68	35.25	5.17	0.77	0.38
Reference Clay + sludge 15%	11.02	1.63	42.85	4.35	0.79	0.31
Reference Clay + sludge 20%	14.03	1.61	47.15	3.95	0.82	0.29

Raut et al. [92], the authors looked at how the bricks' mechanical characteristics were affected by including 70–80% RPMR, 10–20% RHA, and 10% cement. According to their investigation, bricks containing 10% RHA did not see any notable alterations in their physical or mechanical properties. When compared, the use of 20% RHA resulted in a considerable reduction in the bricks' overall quality. Bricks with such a porous structure may have a lower heat conductivity. In addition to that, the compressive strength of these bricks was five times greater than that of the standard ones. According to the findings, optimum bricks are composed of 80 % RPMR, 10 % RHA, and 10 % cement. In their production of porous bricks, Sutcu et al. [93], utilized paper residue in a variety of different proportions. According to the findings of their investigation, adding more of these waste materials to bricks led to an increase in both the bricks' porosity and the amount of water they absorbed. When compared, the compressive strength of the bricks became much lower. The density of these bricks as well as their thermal conductivity both decreased by 33% and 50%, respectively. It is important to point out that the reduction in heat conductivity was found to be much more pronounced in bricks that had pores. These bricks also shrank by an average of 1% to 2%, while the average shrinkage for regular bricks was 3%.

Baskar et al. and Shathika et al. [94, 95], conducted research to determine how the qualities of the bricks were affected by the waste sludge, the fire temperature, and the firing duration. According to their results, increasing the amount of waste sludge as well as the fire temperature led to a reduction in the compressive strength of this particular brick type. At the same time, the compressive strength of the bricks grew in a linearly in accordance with the length of time the bricks were fired. In addition, a higher firing temperature resulted in a lower percentage of water absorption, which led to an improvement in the material's resistance to the effects of the weather. Bricks that contained less than 9% sludge were fired at a temperature of 800 °C for a period of eight hours. Clay bricks were examined by Sutcu et al. [96], using the Taguchi technique to optimize the production process. The bricks were either made with or without olive mill waste. They studied how the bricks' thermal, physical, and mechanical qualities changed depending on the mixture ratios (0, 5, and 10%) and fire temperatures (850 °C, 950 °C, and 1050 °C). Bricks burnt at a temperature of 1050 °C without olive mill waste were found to have the maximum compressive strength according to their research. Due they have the lowest thermal conductivity, the findings also revealed that bricks made with 10% olive mill waste and burnt at 950 °C might be effective as insulation because of their composition.

Yaras and et al. [97], investigated the effects of burning bricks at temperatures of 1000 and 1100 °C on various ratios of carbonation sludge in the bricks. These ratios ranged from 0% to 40%. According to their results, these pore-forming compounds demonstrated their viability by demonstrating their appropriateness based on their mechanical strength and thermal isolation. In addition, the decreased amount of solid waste load in sugar mills implies that these waste materials contribute to the production of bricks that are more sustainable, eco-friendly, and clean. According to the findings of many studies, increasing the carbonation sludge ratio results in an increase in porosity as well as a reduction in the bulk density, thermal conductivity, and compressive strength of the bricks. Singh et al. [98], prepared various mix proportions of 0%, 5%, 10%, 15%, 20%, 25%, and 30% wt% DPMS incorporation in alluvial soil by weight. These proportions were based on the weight of the soil. The following step involved molding mixtures that conformed to IS:456 (75mm x 50mm x 33mm), exposing them to air for 24 hours, and then drying them in an oven at 100 °C for 24 hours. The next step involved adding a suitable amount of water to mixtures that were already conforming to IS:456 and mixing for 30 min. The samples were heated in an oven for two hours at 900 °C, 950 °C, and 1000 °C, respectively. The color of the fired samples shifted from reddish to cream or buff as they were heated, while the color of the fired clay brick specimens ranged from reddish to cream or buff (Table 5 and Fig.11). This alteration occurred as a result of an increased concentration of CaO in DPMS in comparison to an increased concentration of Fe_2O_3 in DMPS [99]. Due to the burning of DPMS and the subsequent formation of pores [92], a rise in DPMS and temperature both result in lighter bricks, which in turn leads to a decrease in density (Table 5). The decreased densities of burned clay brick specimens treated with 30% DPMS amounted to 31.17%, 28.5%, and 28.24%, respectively, when subjected to the target temperatures of 900 °C, 950 °C, and 1000 °C. Due to the production of mullite, the control specimens at 950 °C for two hours of soaking had a maximum density of 1821 $Kgcm^{-3}$ [92]. As a result, the optimal firing temperature was 950 °C, and the optimal soaking time was two hours. Results obtained are similar to those found in the literature.

After adding 30 % of paper residue, Yaras et al.[97], found that the density of the burned clay bricks decreased by 33%. With the addition of only 10% paper mill waste, Goel and Kalamdhad [92], found that there was a 21% decrease in the material's density. As can be seen in Table 5, the amount of firing shrinkage experienced by brick specimens had a modest rise as the proportion of soil replaced by DPMS increased. This increment, however, turned out to be completely insignificant. The spike in water absorption was caused by an increase in both the DPMS and the temperature, which went from 900 to 950 °C (Table 5). However, raising the temperature from 950 °C to 1000 °C did not result in a detectable rise in the amount of water absorbed. This is a result of the burning of organic debris in DPMS during the firing process [93], which causes an increase.

According to ASTM C62 (ASTMC62-17), the maximum allowable water absorption for severe weathering circumstances is 17%, whereas the maximum allowable water absorption for moderate weathering conditions is 22%. IS 1077 (IS 1077, 1992) stipulated that the maximum water absorption for class 10 bricks should not exceed 20%. (i.e., the average compressive strength shall not fall below 10 MPa). Because of this, an increase of 15% in the amount of DPMS shown that it is suitable for water absorption. DPMS replacement results in an increase in porosity (Table 5). Therefore, the decreased thermal conductivity is due to the increased porosity, which may be attributed to the burning of DMPS during the fire process, which leaves behind the pores. In addition to this, the breakdown of $CaCO_3$ into CaO and the subsequent release of carbon dioxide helps the process of pore formation [93]. Because the particles diffuse into the structure as the temperature of the fire rises, the porosity of the material gradually becomes less noticeable (Table 5). The development of mullite was responsible for the increase in strength that was observed [92]. According to the authors, the optimal firing temperature reached 950 °C, while the optimal amount of DPMS was 15 weight %. The specifications established by the Bureau of Indian Standards for class 10 are met by the bricks that were manufactured.

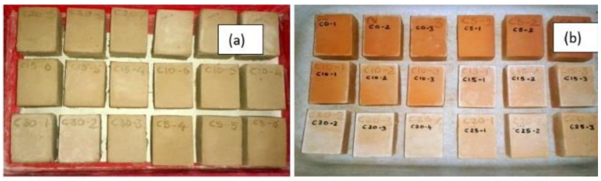

Figure 11. Brick samples (A) before and (B) after firing at 950 °C with different DPMS dosages**.** Figure

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5.3.3. Lightweight bricks-based agricultural waste

The majority of landfills are filled with waste from plants, and these materials have a tendency to accumulate and cause problems with the collection of leachates from landfills. Another issue that might have repercussions on a worldwide scale is the pollution of the air that is caused by the waste products of plants [100]. A solution to this issue may be found, however, in the form of utilizing this waste material as an alternate material for the clay used in bricks [101].

Peels may be produced in the food processing industry at a rate of between 70.000 and 140.000 tons per year [102], which may harm the environment because of the organic waste (microbial spoilage). Such a situation highlights the importance of waste management to boost the economy. Bricks made from plant residue have a larger porosity and lower density than clay bricks, which may help decrease the dead loads of buildings and be advantageous during an earthquake. This is one of the advantages of utilizing plant waste in bricks. Bricks made from plant leftovers are advantageous for use as partition walls in buildings because of their lightweight nature. It is possible that the use of plant residue in construction materials will lessen both the short-term and the long-term negative impacts on the environment.

Table 5. Effect of DMPS in the properties of alluvial soil. Table reprinted with permission from Ref. [98]. Copyright belongs to Elsevier.

Designated	**Alluvial soil (%weight)**	**100**	**95**	**90**	**85**	**80**	**75**	**70**
	DMPS (%weigh)	**0**	**5**	**10**	**15**	**20**	**25**	**30**
Visual appearance	900 °C	Reddish	Reddish	Light Reddish	Light Reddish	Cream color	Buff color	Buff color
	950 °C	Reddish	Reddish	Light Reddish	Light Reddish	Cream color	Buff color	Buff color
	1000 °C	Reddish	Reddish	Light Reddish	Light Reddish	Cream color	Buff color	Buff color
Linear firing shrinkage (%)	900 °C	2.67	2.78	2.84	2.9	2.95	2.98	3.01
	950 °C	2.74	2.83	2.89	2.95	3	3.04	3.06
	1000 °C	2.75	2.83	2.9	2.95	3.01	3.03	3.07
Water Absorption	900 °C	12.8	15.08	17.25	19.12	20.8	24.83	28.64
	950 °C	12.34	14.64	16.62	18.77	20.85	27.26	28.57
	1000 °C	12.36	14.95	16.8	18.9	21.05	25.18	28.92
Average compressive strength (MPa)	900 °C	21.8	17.25	13.84	9.5	7.19	5.21	4.68
	950 °C	22.55	18.11	14.84	10.39	8.15	7.16	5.82
	1000 °C	22.7	18.32	15.04	10.43	8.1	7.45	6.07
Apparent porosity (%)	900 °C	33.61	36.16	38.29	40.2	41.58	45.61	49.42
	950 °C	33.12	35.05	36.65	39.05	42.1	44.83	49.05
	1000 °C	32.84	34.98	37.53	39.03	42.95	44.78	48.28
Thermal conductivity (W/m.K)	900 °C	0.54	0.464	0.394	0.338	0.319	0.281	0.242
	950 °C	0.551	0.468	0.39	0.345	0.31	0.286	0.245
	1000 °C	0.555	0.47	0.39	0.348	0.31	0.285	0.242

Bricks made with plant residue were more cost-effective and affordable than conventional bricks owing to the accompanying decrease in waste, machine use, and consumption of raw material. This reduction in waste, machine usage, and consumption of raw material may, in turn, lessen treatment costs. However, it is still essential to have a suitable location for the disposal of waste and to observe all applicable health and safety regulations, such as always wearing gloves designed for protection. In addition to this, the product, the procedure, and the route of transit all need to be validated by an environmental agency. Because of their durability and the cheap cost at which they can be manufactured, these bricks are an excellent choice for use in constructing partition walls [100].

PPP was studied by Mona et al.[100], who looked at how different replacement rates (3%, 5%, and 7%) affected the soil's clay concentration. Results in terms of physicochemical characteristics were compared to those obtained by making bricks from SOL powder to the specifications set out by the International National Standards Institute for Clay Bricks. A cylindrical mold was then used to give the mixed substances their final form (700mm x 700mm). Twenty-four hours of air-drying time in the box preceded a four-hour burning at a temperature of one thousand degrees Celsius to test the quality of the brick samples. At 7% PPP, the material loses 80% of its compressive strength, 11.9 % of its dry density, 5.4 % of its saturated density, and 81.6 % of its thermal conductivity. This decrease is around 80%, 12.5%, 4.4%, and 76.2% for SOL bricks with equivalent ratios compared to clay bricks, which have a more obvious compressive strength. This decrease in compressive strength increases to a stunning 44.04% when compared to clay bricks when 3% PPP is employed. When using SOL, the highest possible percentage is reached simultaneously. From what we can see, the PPP was much more effective than the SOL in reducing the bricks' compressive strength. One possible explanation is that the PPP's higher pore capacity is due to its lower SiO2 content than the SOL's [103]. Lower percentages of SOL showed bigger voids and more uniform pore size distribution [104], whereas 7% PPP showed larger voids and less uniform pore size distribution.

As further proof of the density difference between PPP and SOL bricks, its chemical structure makes it burn slower. Soundproofing, water absorption, the percentage of soluble salts, and porosity are all improved by 27%, 46%, 26.32%, and 18.62%, respectively, when the PPP content is raised. The percentage increases are around 32.4%, 51.6%, 34.21%, and 13.68% for bricks with 7% sour orange, respectively, as compared to clay bricks. The presence of more residue in the bricks may increase their void area, which in turn increases their ability to absorb water. Compared to SOL bricks, those made with 3% and 5% plant waste have a more uniform and shallower void. In contrast, bricks made from 7% plant residue are superior.

Bricks with a PPP content of 3% have a compressive strength of 8.89 MPa, whereas those with a PPP content of 5% have a compressive strength of 4.99 MPa. These numbers are both superior than the SOL minimums. In our tests, we found that bricks with a higher porosity were more effective in dampening noise than their solid counterparts. This held true even when the PPP was held constant. The best increase in soundproofing was seen for bricks with 3% PPP, with a reading of 10.16 dB at 2000 Hz and 5000 Hz. When the amount of plant residue is raised from 3% to 5% and 7%, the transmitted sound intensity is decreased by 18.62% and 10.63% at 5000 Hz and 4000 Hz, respectively. The percentage savings is about 13.6 %, compared to 6.8 % for bricks using SOL [10]. Pérez-Villarejo et al. [105], used waste products from olive cultivation (i.e., OP, OL, and OW with a particle size of 0–2mm) to replace the raw clay material (Fig.12A). Olive waste was ground to obtain a 0–2mm particle size. Different replacement percentages of olive waste (7.5%, 15%, and 25% by volume), in the presence of 10wt% water and 2.5 MPa forming pressure, were mixed with the clay. The molded green bodies (60mm x 30mm x 10mm) were fired at 850 °C for 30 minutes (Fig.12B). The olive wastes have high heating values; thus, they can reduce the firing temperature and production costs.

The lowest olive by-products volume (7.5%) demonstrated the highest compressive strength of 35.7 MPa, 40.9 MPa, and 34.9 MPa for OL, OP, and OW, respectively (Fig.12C). However, the highest values reduced the compressive strength. When compared to pure clay, the insertion of 7.5% OP, OW, or OL resulted in a reduction of bulk density that ranged from 5.2% to 8.6% lower than that of pure clay. Bulk density is directly related to compressive strength. In most cases, the presence of open pores lowers the compressive strength of the ceramic tiles, which is caused by the pieces' uneven form and other microscopic flaws [106]. The values for the ceramic bricks fell below those of the received clay-like earth material. This development was to be expected, due to replacing the original raw clay with different percentages of organic matter, which, when sintered, resulted in porosity.

However, the found values far exceed the minimum value of 10 MPa and 20 MPa required by the EN-772-1 [107]and ASTM C62-10 [108]standards for bricks exposed to ordinary and harsh weathering, respectively. Increased percentages of olive by-products decreased thermal conductivity in relation to the pure clay controls (Fig.11A).

(A)

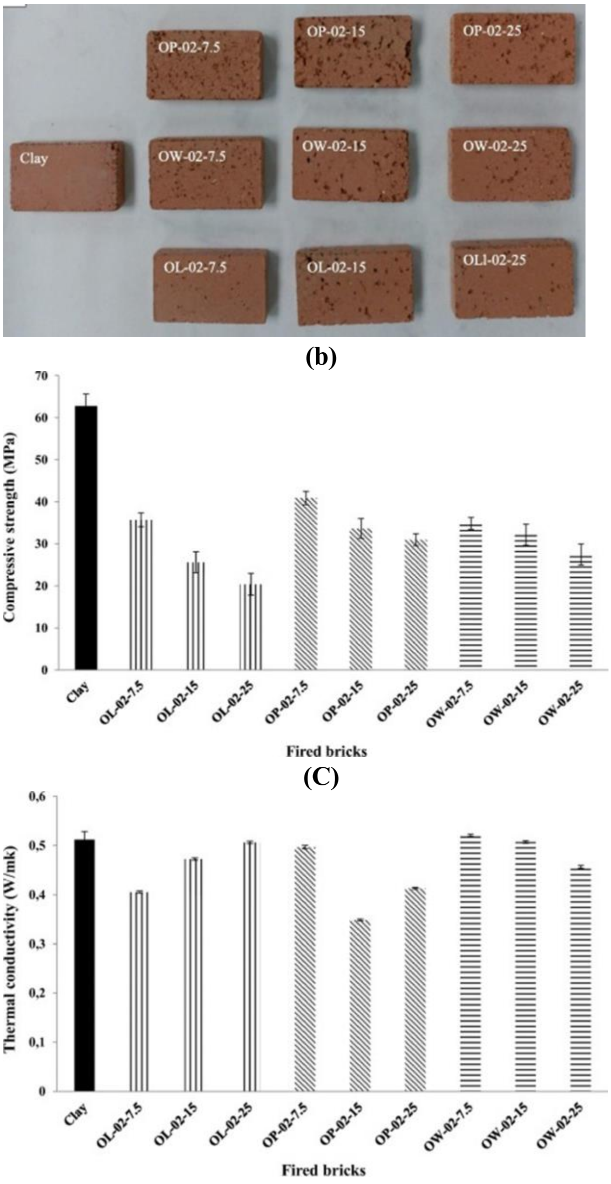

Figure 12. Photographs of by-products (A), photographs of fired bricks (B), effect of by-products in compressive strength (C), effect of by-products on thermal conductivity (D). Figure reprinted with permission from Ref. [105]. Copyright belongs to Springer.

Houssame et al. [109], assessed the effect of replacing unfired clay bricks with (0, 1, 3, 7, 15, and 20wt%) of recycled date pits waste. The molded samples (160mm × 40mm × 40mm) were pressed at 6.5 MPa following the ASTM C216. The compressive (4.02 MPa), flexural strengths (0.98 MPa), and bulk density (1.63 gcm^{-3}) decreased to 20% of date pits waste compared to the figures of 6.17 MPa, 4.65 MPa, and 1.76gcm^{-3} for the pure clay bricks samples. Furthermore, at 20%, the waste porosity and capillary water absorption coefficient increased from 1.17$gcm^{2}min^{0.5}$ and 26.5$gcm^{2}min^{0.5}$ of clay brick sample-free date pits waste to 18.51% and 49.75$gcm^{2}min^{0.5}$, respectively. The thermal conductivity (0.33Wm^{-1} k^{-1}) and specific heat capacity (0.69KJ Kg^{-1} K^{-1}) were reduced in comparison to the clay pure bricks samples (0.52$Wm^{-1}k^{-1}$) and (0.57KJ Kg-^{1} K^{-1}), respectively. A simulation in a reference house revealed that thermal cooling (68%) and heating loads (47%) helped save energy. Bricks that were manufactured were categorized as lightweight building materials in accordance with Moroccan standards NM 10.1.009–2014, which are comparable to American standards ASTM C20-00. Estimates suggest that producing unfired bricks saves approximately 70% in energy compared to fired ones. Kazmi et al. [110, 111], replaced clay with Sugarcane bagasse ash SBA and RHA (5, 10, 15 wt.%). Melded brick specimens (228mm x 114mm x 76mm) were fired at 800 °C in a furnace for 1.5 days.

Increasing the fired clay bricks' SBA and RHA decreased compressive strength, flexural strength, and thermal conductivity and increased water absorption and porosity. Brick specimens incorporating SBA and RHA up to 15% reduced the compressive strength (up to 5.53 MPa), flexural strength (up to 0.83 MPa), and thermal conductivity (up to 0.37$Wm^{-1}K^{-1}$) compared to the pure fired clay bricks of 9.5 MPa, 1.5 MPa, and 0.52$Wm^{-1}K^{-1}$, respectively. Furthermore, brick samples demonstrated high water absorption (up to 23.86%) and porosity (up to 40%) compared to the fired clay bricks of 16% and 30%, respectively. The produced brick achieved the minimum requirements indicated by ASTM C67 [112].

Turning this waste to good use keeps landfills from filling up and leads to more eco-friendly, energy-saving building supplies. Clay and rice straw were the subject of research by Elwan et al.[113]. The firing temperature was 900 °C. Researchers found that although adding straw enhanced porosity, it also reduced strength. Fly ash was then added to the mix, and the result was a boost in strength without a corresponding loss in porosity. In a similar vein, Ivanovich et al. [114], found that adding straw either before or after burning would provide comparable results, and they advised doing so in order to take use of the high silica concentration of the ash. There have been a lot of research done on the benefits of bagasse and its ash. Using small amounts of bagasse has been shown to promote porosity without reducing compressive strength. Kazmi et al. [115] and Saleem et al. [116] and at 10% by Jambuala et al. [117], all placed this limit at 5% (by weight).

Lightweight bricks' qualities were investigated by Georgiev et al.[118], who looked at how adding wheat straw and sunflower seeds to clay changed things when the mixture was burnt at 900 °C. They found that by using only 8% straw devoid of seeds, the heat conductivity and porosity of the final product were both drastically improved. When compared to the baseline value established by ASTM C62-17 [119], the equivalent compressive strength was still higher. The pore-forming properties of water hyacinth were studied by Goel et al. [120]. Based on their findings, it is advised that 10% waste be used to create light bricks in accordance with the approved norms and that the mixes be fired at 900 °C. Sawdust has also been used to create lightweight clay bricks; Low et al.[121], mixed sawdust and glass powder dust to dry-press clay into bricks. Porous bricks with a compressive strength of more than 30 MPa were supposedly obtained.

Chee-Ming [122], made both unfired and fired clay bricks using oil palm fruit and pineapple leaves. He found that fibers had a far larger impact on porosity in burnt bricks than in unfired specimens, all while keeping the strength at 5.2 MPa. Elinwa [123], made lightweight bricks out of sawdust ash and burned them at several temperatures. She suggested burning the bricks at 600 °C to achieve high porosity while maintaining decent strength. The sawdust ash would make up 10% of the mixture. However, Chemani et al. [124], found that including 9% sawdust into clay and burning at 900oC increased the bending strength to about 14 MPa.

As an alternative, Beal et al. [125], suggested utilizing wood ash at a concentration of 25% by weight to create bricks with poor strength but low heat conductivity. Kadir et al. [126, 127], looked into recycling cigarette butts into lightweight bricks. They sterilized the waste materials by heating them to 1050 °C for twenty-four hours and then storing them in plastic bags. According to the findings, the degree to which these bricks were compacted was reduced by between 8% and 30% overall, depending on the waste ratios. It's possible that this reduction led to an increase in water absorption, which was particularly noticeable in bricks that included 10% cigarette butts. In addition, the presence of 10% cigarette butts resulted in a reduction of 30% and 80%, respectively, in the compressive strength of the bricks. The thermal conductivity of bricks reduced as the proportion of cigarette butts used in their production increased. For instance, increasing the percentage of cigarette butts in a material from 5% to 10% lowers its thermal conductivity by roughly 51% and 58%, respectively, which results in considerable energy savings.

Semi-dry pressed bricks with varied amounts of waste marble powder and two different firing temperatures (950 °C and 1050 °C) were studied by Sutcu et al. [120]. They reasoned that because this trash could produce pores, it could have some insulating properties. Bricks with a larger proportion of waste marble powder were less dense, had less compressive strength, and had poorer thermal conductivity, while also being more porous. There was a significant difference in heat conductivity between bricks with a marble powder residue of 35% and those without any marble powder residue at all. Semi-dry pressed bricks made with varying amounts of leftover marble powder and two different fire temperatures (950 °C and 1050 °C) were analyzed for their properties by Sutcu et al. [120]. They reasoned that since it contains waste material, it may behave as a pore-maker and have heat-insulating qualities. The use of discarded marble powder increased the bricks' porosity, but lowered their bulk density, compressive strength, and thermal conductivity. The thermal conductivity of bricks with a 35% ratio was the lowest, while that of bricks made without waste marble powder was the greatest.

Suctu et al. [128], investigated examined bottom ash and fly ash bricks fired at 950 and 1050 °C to determine their individual properties. Bottom ash was shown to have no effect on the bricks' water absorption, bulk density, apparent porosity, or thermal conductivity, regardless of the percentage employed. Increasing the fly ash ratio led to better water absorption and porosity, but at the expense of a significant decrease in bulk density and thermal conductivity. Bricks that were heated to 1050 °C were less porous and water absorbent than bricks cooked to 950 °C, but they had higher thermal conductivity and bulk density. It's possible that this shift originated from the bricks being more densely packed as a consequence of being heated to higher temperatures. Also, increasing the ratio of fly ash to bottom ash significantly reduces the compressive strength of bricks. Despite this, bricks manufactured with 5% fly ash, 5% bottom ash, and 10% bottom ash had similar compressive strength, water absorption, and porosity. Not only did these bricks have lower bulk density and thermal conductivity than the control bricks, but they were also more energy efficient.

5.3.4. Lightweight bricks-based polymers

Several forms of foamed polymers have been studied as potential pore producers in clay bricks in a number of studies. Plastic materials are used in a wide variety of industries because of their simple manipulation and lightweight composition [129]. Some of these industries include packaging and construction. In 2018, the yearly manufacturing of plastics throughout the globe surpassed 359 million metric tons, with 79% of that amount ending up in landfills.

On the one hand, HDPE materials rank fourth within the list of most produced plastic materials worldwide, as shown by an annual production of 51.33 million metric tons in 2017; according to estimates, the figure would rise to 66.69 million metric tons by 2020 [130]. On the other hand, the annual production of LDPE materials ranks fifth within the list of most produced plastic materials worldwide, as shown by an annual production of 51.33 million tons in 2017. In the construction industry, the use of polymeric additives may lead to a reduction in the raw materials used, the amount of energy consumed, and the impact on the environment, as well as a contribution to the development of inexpensive clay-based bricks with a lightweight structure and improved thermophysical properties. [129].

Houssame et al. [129, 130], assessed different proportions of polymeric wastes (HDPE and PET) (0%, 1%, 3%, 7%, 15%, and 20wt. %) with three grain-size additives ($\delta \leq 1$mm; 1mm < $\delta \leq 3$mm and 3mm < $\delta \leq 6$mm) replacing the clay weight (size = 50µm). The process utilized the melting compounding technique to prepare a brick sample, in which the mixture was heated at 300 °C for 15 minutes with continuous agitation at 95rpm. Water was added to the mixture and molded (120mm × 120mm × 40mm) under 6.5 MPa. The molds were dried from 20 °C to 50 °C to remove moisture. An increased porosity level would occur as the percentage and size of the additive rose.

Also, the greater Melt Flow Rate index of HDPE additions improves the clay-polymer mix characteristics, whereas the PET additives resulted in more porous samples. And since HDPE additives are denser than PET ones, the volume ratio of HDPE to clay is better than the volume ratio of PET to clay. What this means is that HDPE additive samples have greater intercalation and better polymer mixing since fewer flocculants are generated per unit mass compared to PET additive samples.

Density readings taken of the produced specimens reveal that they fall into the category of lightweight bricks, with a bulk density of less than 1.75gcm^{-3}. The use of smaller polymeric-grain additions ($\delta \leq 1$mm) as opposed to larger ones (3mm <δ> 6mm) resulted in an estimated 17% and 28% improvement in the capillary water absorption coefficient and compressive strength parameters, respectively. Distribution and intensity of porosity are to thank for this enhancement; a more porous brick sample has a higher capillary water absorption coefficient and a lower compressive strength. The specific heat capacity and thermal conductivity of specimens are improved by using a bigger grain size and a high polymeric waste additive content. This method enhances the thermal characteristics of the samples [45], resulting in significant increases in thermal conductivity (Table 6). This is because more flocculants were generated in the brick's matrix during melt compounding preparation mixing, as a result of interactions between clay and polymers with higher plastic additive particle sizes. This resulted in samples of brick with increased porosity, which in turn increased their thermal conductivity and specific heat capacity. By increasing the brick's mixture packing with a strong void filling, finer grain particles increased cohesive binding in the clay polymer matrix, leading to low porosity percentages and therefore reduced thermal characteristics in the resulting specimens. Akçaozo ¨ Glu et al. [131], showed that the heat conductivity of a brick decreases as the amount of plastic additives increases.

Bricks with a 30% plastic additive content had an approximate 34.6% increase in thermal conductivity after going through this procedure. More grain size additions and thicker exterior walls improve thermal stability with a longer time lag and a smaller decrement factor. Also, the time lag and decrement factor were 13.5 h and 0.148, respectively, for a 0.3 m thick exterior wall built of PET-based samples, whereas the corresponding values for the reference values were 8.99 h and 0.346. This research suggests significant improvements in dynamic thermal inertia qualities, with time lag improvements of up to 50% and decrement improvements of up to 57% when compared to reference values.

Veiseh et al. [132], examined the impact of adding polystyrene to clay at varying concentrations (from 0% to 2%) on green and bricks burnt at temperatures ranging from 900 to 1050 °C. At a 2% water addition, the absorption values reached 25% while the compressive strength dropped to just 9 MPa. Polypropylene foamed plastic, created by Kanshidurai et al. [133], by combining polypropylene with clay and fly ash, was studied. According to their data, the greatest compressive strength of the burned mixes was only slightly more than 6 MPa, which is much below the ASTM limits [119]. Bwayo et al. [134], investigated the impact of agricultural waste on the bricks' specific heat capacity. Adding 20% sawdust waste to the mix increased the porosity and specific heat capacity of the bricks by 21% compared to the control sample. Additionally, higher sawdust additions improved the specimens' thermal performance. Based on the results of these studies, we constructed a model house with external walls of varied thicknesses (0.20 m, 0.25 m, and 0.30 m) [126]. This house is six meters squared (2 x 5 x 2 ft).

5.3.5. Lightweight bricks based on cementitious materials

Cementitious bricks have mostly replaced fire-made kiln bricks in recent decades [135] because to the massive amounts of energy required for burning and the pollution it creates. To classify these materials, we look at the reaction between silica and calcium oxide, which results in calcium silicates that with hydration, evolve into robust materials. There are various possible mechanisms for pore development in bricks. There are two kinds of bricks that fall into this category: sand lime bricks and lightweight cement bricks.

5.3.5.1. Lightweight sand lime bricks

Typically, this kind of brick is produced by autoclaving under supersaturated steam conditions. Bricks crushed at 20 MPa and steam autoclaved for six hours at 1.5 MPa were produced by T. Ciçek et al, [136], who utilized a mixture of lime, sand, and fly ash. The manufactured bricks had a satisfactory strength of 10.25 MPa and a low bulk density of 1.14 g.cm^{-3}. However, Sahu et al. [137], suggested settings for the particle size distribution of sand and its ratio to slaked lime to get autoclaved bricks with low density and enough strength. Wahane [138], looked at how adding aluminum powder into the mix might affect the rate at which hydrogen was produced by reacting with lime. Slaked lime, sand, cement, and aluminum powder were all suggested as ingredients in the study's proposed formula.

5.3.5.2. Cement-based bricks

Lightweight materials, such as agricultural waste or foamed polymers, are added to cement bricks to generate porosity. We looked at how adding various low-density waste materials impacted the bricks' bulk density and compressive strength. Bricks with low thermal conductivity were made by Singh et al. [139], using a mixture of clay, perlite, lime, gypsum, and cement. Although the compressive strength decreased from 10.38 MPa at 5% perlite to 3.3 MPa at the 25% level, the benefits of increased porosity and heat resistance outweighed the drawbacks. In a later study, Ling et al. [140], combined rice husk ash and expanded perlite with cement and sand to create a lightweight concrete. To the tune of 20%, they found that RHA could stand in for sand. Lightweight concrete was developed by Mehmannavaz et al.[141], who substituted palm oil ash and pulverised fuel ash for cement. After 28 days of curing, the density was optimized at a value of 1095kgm-3 (compressive strength of 7.1 MPa) thanks to a 50% palm oil ash replacement.

Table 6. Effect of HDPE and PET in the properties of clay [129, 130].

Brick samples		Porosity (%)	Bulk density (g/cm^3)	Capillary Water absorption coefficient (g/cm^2.min0.5)	Compressive strength (MPa)	Specific heat capacity (KJ/Kg.K)	Thermal conductivity (W/m.K)
Reference Clay		1	1.78	27.95	5.62	0.58	0.48
Reference Clay + 1% HDPE	$\delta \leq 1$ mm	4	1.74	30.03	5.04	0.59	0.46
	1 mm < $\delta \leq 3$ mm	6	1.71	35.37	4.55	0.61	0.41
	3 mm < $\delta \leq 6$ mm	11	1.67	37.14	1.05	0.63	0.38
Reference Clay + 3% HDPE	$\delta \leq 1$ mm	6	1.72	32.25	4.61	0.63	0.43
	1 mm < $\delta \leq 3$ mm	9	1.67	37.14	4.30	0.64	0.38
	3 mm < $\delta \leq 6$ mm	14	1.64	39.19	3.91	0.66	0.33
Reference Clay + 7% HDPE	$\delta \leq 1$ mm	9	1.67	37.64	4.34	0.68	0.33
	1 mm < $\delta \leq 3$ mm	11	1.66	42.75	4.08	0.69	0.30
	3 mm < $\delta \leq 6$ mm	19	1.59	47.68	3.63	0.71	0.28
Reference Clay + 15% HDPE	$\delta \leq 1$ mm	14	1.66	45.21	3.45	0.77	0.28
	1 mm < $\delta \leq 3$ mm	19	1.6	51.16	3.04	0.78	0.25
	3 mm < $\delta \leq 6$ mm	6	1.53	58.75	2.63	0.80	0.24
	$\delta \leq 1$ mm	19	1.62	48.13	3.01	0.81	0.25

Brick samples		Porosity (%)	Bulk density (g/cm^3)	Capillary Water absorption coefficient (g/cm^2.min0.5)	Compressive strength (MPa)	Specific heat capacity (KJ/Kg.K)	Thermal conductivity (W/m.K)
Reference Clay + 20% HDPE	1 mm < δ ≤ 3 mm	22	1.57	55.14	2.73	0.84	0.23
	3 mm < δ ≤ 6 mm	28	1.51	61.12	2.20	0.86	0.20
Reference Clay + 1% PET	δ ≤ 1 mm	8	1.71	33.69	4.50	0.60	0.43
	1 mm < δ ≤ 3 mm	10	1.69	37.25	4.15	0.62	0.39
	3 mm < δ ≤ 6 mm	17	1.63	39.20	3.54	0.65	0.35
Reference Clay + 3% PET	δ ≤ 1 mm	11	1.66	35.62	4.29	0.64	0.40
	1 mm < δ ≤ 3 mm	15	1.65	39.5	3.40	0.66	0.35
	3 mm < δ ≤ 6 mm	22	1.61	42.33	2.63	0.67	0.30
Reference Clay + 7% PET	δ ≤ 1 mm	15	1.62	40.82	4.12	0.69	0.34
	1 mm < δ ≤ 3 mm	19	1.6	47.15	3.14	0.70	0.29
	3 mm < δ ≤ 6 mm	26	1.57	53.77	2.35	0.73	0.26
Reference Clay + 15% PET	δ ≤ 1 mm	22	1.59	56.83	3.17	0.78	0.27
	1 mm < δ ≤ 3 mm	25	1.55	56.13	2.81	0.79	0.24
	3 mm < δ ≤ 6 mm	28	1.49	60.12	2.01	0.81	0.21
Reference Clay + 20% PET	δ ≤ 1 mm	25	1.53	52.92	2.82	0.83	0.22
	1 mm < δ ≤ 3 mm	28	1.49	61.12	2.55	0.85	0.21
	3 mm < δ ≤ 6 mm	29	1.44	64.15	1.71	0.89	0.18

Lightweight bricks were made by combining cement, sand, and bagasse ash, as described by Singh et al. [142]. When the bagasse ash content was increased to 35%, the compressive strength dropped precipitously from 14.4 MPa to 5.25 MPa, and the density also dropped significantly. Chen [143], mixed carbon ash from a facility that processed both organic and inorganic plastic waste with cement and sand. Around 40% of the total was composed of ash. Bulk density varied between 714 and 1090g/cm^3, and compressive strength decreased slightly from 8.7 to 10.9 MPa as ash concentration increased. The temperature gradient was between 0.31 and 0.43 watts per meter per kelvin. To make their lightweight bricks, Azmi et al.[144], used recycled polyethylene terephthalate plastic with cement and sand. After 28 days of curing, the water absorption rose from 4.1% to 7.6% when the terephthalate content was raised from 0% to 2.5%, while the compressive strength was reduced. On the other hand, the authors omitted information on the bulk density of the mixture and how an increased plastic component affected it. Al-Hazmy [145], assessed the thermal performance of bricks packed with air and insulation in a variety of combinations. Air-filled hollow bricks showed considerable improvements in thermal performance. Hollow bricks filled with insulation reduced heat loss by 36%[10, 145].

The thermal characteristics of concrete hollow bricks were studied in depth by Martines et al. [146]. Both computational and empirical methods were used to examine the impact of insulating material within hollow bricks of varying geometries on thermal resistance (see Fig.13). In addition, research established that the minimum and maximum thermal resistances (between A1 and D4) were 0.207m^{2}KW^{-1} and 1.050m2KW^{-1} (Table 7). Thermal performance of hollow bricks filled with air, glass wool, polystyrene balls, and recycled foam polyurethane was studied in similar research [74].

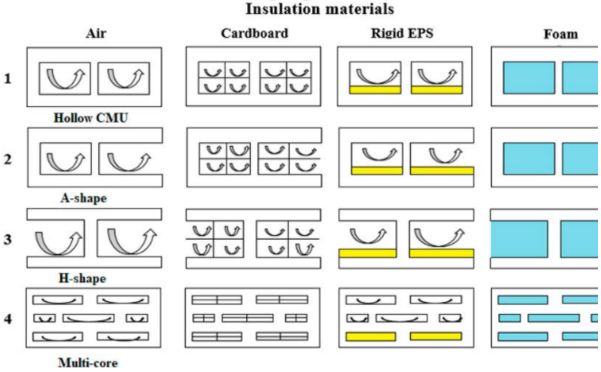

Figure 13. Hollow bricks with diverse geometric infill materials [10].

Table 7. Air-filled hollow bricks, cardboard, stiff expanded polystyrene, and foam are compared for their thermal properties [10].

Brick model	R-value (mKW^{-1})	Improvement (%)
A-1	0.207	
A-2	0.222	7%
A-3	0.248	20%
A-4	0.327	58%
B-1	0.289	
B-2	0.337	16%
B-3	0.401	39%
B-4	0.427	48%
C-1	0.310	
C-2	0.387	25%
C-3	0.542	75%
C-4	0.395	27%
D-1	0.415	
D-2	0.591	42%
D-3	1.050	153%
D-4	0.495	19%

According to the investigation, the thermal conductivity of mineral wool-filled bricks decreased by 60% compared to the one filled with air (Table 8).

Table 8. Thermal characteristics of hollow bricks that have been filled with various materials [10].

Hollow filled with	Air	Polystyrene balls	Hydrophilic mineral wall	Recycled foam
Effective thermal conductivity (Wm^{-1}K^{-1})	0.124	0.085	0.074	0.081
R-value (m^{2}KW^{-1})	4.03	5.88	6.76	6.17
U-value (Wm^{-2}K^{-1})	0.25	0.17	0.15	0.16

Ultimately, the physical, mechanical, and thermal properties of clay bricks substituted with various waste materials are summarized in the table 9 after a review of the relevant literature.

Table 9. The physical, mechanical, and thermal properties of clay bricks replaced with different waste materials

	Waste material	**Compressive strength (MPa)**	**Water Absorption (%)**	**Bulk density (Kg/m^3)**	**Thermal conductivity (W/mK)**	**Ref**
1-	Diatomaceous earth residues (3 – 10%)	12.7 - 9.5	-	1770 - 1670	0.65-0.45	[147]
2-	Rice husk (10 – 30%), wood ash wastes (10– 30%)	53.4 - 13.5	21.2%- 32.9%	1839 – 1394	0.68-0.34	[148]
3-	Waste coal (up to 30 %)	-	11.8 – 13.2	1040 - 1250	0.19 - 0.23	[149]
4-	Olive mill waste (0, 5, and 10%)	36.9 - 10.26	14.5% - 32.5%	1920 - 1450	0.638 - 0.436	[96]
5-	Olive pomace bottom ash (10, 20, 30, 40, and 50%)	33.9 - 10.5	19% - 3 1.5%	1635 - 1278	0.143 -0.166	[150]
6-	Kindling from vine shoots (5, 11, and 17%)	38.04 – 1.556	16.93% - 36.04%	1684 - 1124	0.738 - 0.208	[151]
7-	Wheat straw, olive stone flour (4% and 8%), and sunflower seed cake (4%)	5.3 – 10.9	17.8% - 30%	1700 - 1460	0.55-0.36	[152]
8-	Marble powder (0, 5, 10, 15, 20, 25, 30, and 35%)	34.2 - 8.2	10.9% - 26.9%	2050 - 1590	0.97 -0.40	[153]
9-	Biomass ash (100- 50%), and dust filter (0 – 50%)	17.3 – 5.9	19.8% - 27.5%	1471 - 1346	0.655 - 0. 42	[154]
10-	Glass powder (20 – 35%) and palm oil fly ash (20 – 35%)	15.39 – 7.21	11.48% - 18.5%	1628 – 1338.7	0.39	[155]
11-	Sawdust (5 - 20 vol%), wood ash (5 - 15 vol%), and lime mud (5 -15 vol%)	0.83 - 7.56	11.5% - 24%	2080 - 1380	0.55 – 1.12	[156]
12-	Bio - briquette ash (5 – 55%)	3.64 - 4.19	13% - 25%	1470 - 1170	0.65-0.36	[157]
13-	Recycled fine aggregate (25 -100%)	12.75 – 20.98	9.33- 11.46 %	1968 – 1962	0.82	[158]

5.3.6. Lightweight bricks based Geopolymer

Producing fired bricks requires a lot of energy because of the high kiln temperature (900 °C to 1000 °C) and produces a lot of GHG (such as CO_2 and NO_x)[159-161]. Due to the high energy needs and the use of natural resources, clay and shale are the primary raw materials used in brick manufacture, neither of which are considered eco-friendly or economical [162, 163]. Consequently, there has been a rise in interest in discovering replacement building materials to meet these issues. There is a lack of landfill space, and studies have shown that industrial waste disposal practices are a major contributor to this problem [164].

Reduced landfill trash, lower natural resource consumption, and lower quarrying operating costs are all possible outcomes of using waste materials in brick manufacture [165]. In addition, this method helps lessen energy needs since it requires less burning and makes more efficient use of resources for trash disposal. Bricks have been made of a variety of byproducts, including fly ash, slags, mine tailings, rice husk ash, cotton waste, oyster shell, and wood sawdust [166-178].

New geopolymerization process allows for the production of bricks from industrial wastes that are naturally abundant in aluminosilicate minerals. The procedure [179] highlights the financial and ecological advantages of rubbish recycling. You may get a stable material with an amorphous polymeric structure by reacting the aluminosilicate components with a highly concentrated aqueous alkali hydroxide or silicate solution [159-161]. During the process, the geopolymer gel network produces the sodium aluminosilicate hydrate gel (N-A-S-H) with a tetrahedral network of SiO_4 and AlO_4 with shared oxygen atoms, resulting in a three-dimensional structure [164].

Consequently, while making a geopolymer, it is important to keep the ratio of silica to alumina constant. The relevance of alkali solution in the development of the

N-A-S-H geopolymer network is shown by the high concentration of this solution. Previous research with multi-purpose 6M, 8M, 10M, and 12M sodium hydroxide molarity solutions[180-183] has shown promising results.

As a result of the lack of aluminosilicate in many geopolymer precursors, supplementary ingredients are often needed to boost the physical and mechanical characteristics of geopolymers or created geopolymers pastes with a low SiO_2/Al2O_3 (Si/Al) molar ratio [184]. A geopolymer with a high surface area is created at this molar ratio, which improves its adsorption ability [185, 186]. Mixtures of fly ash, electric arc furnace slag, and leftover foundry sand were used to create geopolymer bricks by Apithanyasai et al. [164], for use in pavement applications. Waste foundry sand, on the other hand, is deficient in both alumina and calcium, necessitating the addition of fly ash and electric arc furnace slag in varying percentages in order to increase the alumina to calcium ratio and, hence, the compressive strength. Fly ash-based geopolymer bricks were prepared by Ibrahim et al.[187] using caustic soda and sodium silicate as an activating solution, with the addition of an unnamed foaming ingredient at a concentration of 5% to 10%. Densities of their samples were about 1400–1500 kg/m3 and compressive strengths ranged from 5 MPa–10 MPa, depending on the amount of foaming agent used. Using styrofoam as a pore producing agent at concentrations up to 0.9%, Risdanareni et al [188], found same outcomes. The high cost of NaOH (10M) is a major obstacle to commercializing this method.

However, Roviello et al. [189], were able to successfully construct hybrid geopolymer-based foams with densities between 250 and 850 kgm^{-3}, exhibiting desirable mechanical characteristics, fire resistance, and low thermal conductivity. When making geopolymers, hydrogen peroxide was utilized as a foaming agent to create porosity [190-194]. The high molarity of NaOH (often >10M) might be expensive to work with when using these technologies. Using discarded clay bricks, slaked lime, aluminum scraps, and de-aluminated kaolin, K.A.M.El-Naggar et al. [195] created insulating geopolymer bricks. Their research showed that by using aluminum scraps at a weight percentage of 5% and replacing 15% of the clay brick waste with de-aluminated kaolin, the porosity could be increased to almost 50%, resulting in bricks with densities below 1000 kg/m^3. These bricks have a compressive strength of about 1.4 MPa and a thermal conductivity of as little as 0.26 $W.\ m^{-1}.K^{-1}$.

6. **Conclusion**

Heat transport into buildings in hot desert environments is largely influenced by the building envelope. For similar reasons, walls are important heat conductors because of their enormous surface area and high thermal conductivities. As a result, researchers have created a wide variety of light-weight bricks to reduce the interior's vulnerability to heat stress. Large porosity and poor heat conductivity are only some of the characteristics that make lightweight bricks a versatile building material. The following are the main types of lightweight brick that could be gleaned from previous studies:

- There has been no previous research on the thermal properties of fired lightweight brick that is more suited to a hot, arid region because of its low weight, which is caused by a high porosity percentage and hence reduces the heat conductivity.
- Several types of combustible materials, such as fuel waste, sludge, agricultural waste, polymers, and cementitious materials, could be used to make porous lightweight bricks.
- Previous studies have shown that adding more sludge to the process of making lightweight bricks makes the bricks more porous and decreases their ability to transfer heat.
- A light-weight brick has been made from a variety of agricultural waste materials. The most common agricultural waste materials utilized to improve energy efficiency by increasing porosity and decreasing thermal conductivity are waste products from olive cultivation, recycled date pit waste, sugarcane bagasse ash, potato peel powder, sour orange leaf, and rice husk ash.
- Using polymeric additives in the construction industry could cut down on the amount of raw materials, energy used, and damage to the environment. It could also help make clay-based bricks that are cheaper, lighter, and have better thermophysical properties. The process of making a lightweight brick, which involves replacing the clay weight with polymeric additives and using melting compounding to make a sample brick, causes the porosity level to rise as the percentage. When larger grains and more polymeric waste are used as additives, the measured specific heat capacity of the specimens goes up and the thermal conductivity goes down. This method improves the thermal

properties of the samples.

- Cementitious bricks have replaced kiln-fired bricks because they are less expensive and less polluting. The lighter building materials in this category include sand-lime and light cement bricks. It is possible for different types of pores to form in different types of brick, depending on the type of brick used.
- Industries discard a lot of waste, which leads to both environmental threats. Recycled waste can be used to manufacture bricks, which could help with overflowing landfills as well as reducing the consumption of natural resources and the associated expenses. Another benefit is that this method of waste disposal conserves energy by not relying on burning, and it also makes better use of available resources. Waste goods such as fly ash, mine tailings and tailings and cotton waste have all been used to replace or enhance traditional brick materials by researchers. Mechanical, physical, and thermal qualities have all seen a substantial improvement throughout the years.

As a conclusion, lightweight brick is the best alternative to traditional bricks. You might utilize a variety of wastes to make it. Building insulation and energy efficiency could be improved by using lightweight brick.

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