

Original research

Thermal and Energy Efficiency of Roof Tiles Fabricated from Crushed Aluminum Slag and Kaolin Clay for Social Residential Buildings in Egypt

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Abstract:

In Egyptian climates, an efficient insulating system could reduce air conditioner energy demand. Building insulation, especially waste-based insulation owing to its low cost, wide availability, and treatment of waste, became interesting. Thus, this study examined the effect of roofing tile samples made from 40% waste aluminum crushed and kaolin clay with different firing temperatures (900 °C, 1000 °C, and 1100 °C) on the internal air temperature and energy needed to cool social residential buildings built without climatic considerations in Egyptian climatic regions. Design-Builder (DB) was used to simulate the study regions for environmental performance and cooling effect. The study model was validated by comparing monthly energy use data with Aswan residential unit electricity bills. Sample S2, fired at 1000 °C, exhibited the lowest thermal conductivity and saved 4.7% to 13.33% of cooling energy across all climatic regions. In hot deserts, the roof tile sample (S2) could save till 8.99% of cooling energy. Aswan, a desert city, saves the most energy despite having a slight improvement rate 8.23% compared to other cities. Finally, the study supports sustainable design in the present and future. The sustainable design could substantially lower interior thermal temperature and cooling energy.

Keywords: Building insulation; Design Builder; Building envelope; Cooling energy; Industrial waste.

1- Introduction

1.1. Energy consumption in the buildings

Energy consumption has sharply increased in recent years as a result of population growth, urbanization, and climate change (Hamdy et al., 2020; Ragab, 2020). Every day, 200,000 people are born (Organization, 2007), which has forced the creation of new cities, On the other side, the world population is expected that will increase by two billion people in the next 30 years (Statistics, 2021), which means that the world population will increase from 7.7 billion at the present time to 9.7 billion by 2050, and the number will reach 11 billion by the year 2100.

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As the United Nations Development Program (UNDP) revealed irrational differences between the number of births and population rates between regions of the world (Sachs et al., 2021), and these differences are accompanied by an unfair sharing of global resources. Moreover, the rapid increase in urbanization and the resulting influx of new building occupants has contributed to the world's overpopulation crisis as well as an increase in energy usage is a direct effect of all these issues (King et al., 2015). Energy use in residential buildings accounts for nearly half of Egypt's overall energy consumption. 2020/2021 (EEHC, 2021). The residential building sector in Egypt consumes 62393 kWh of distributed electricity, which presented 40.5% of the total energy.

Half of the energy used worldwide now is consumed by approximately 50 million buildings (Sachs et al., 2021). How to use building data successfully presents the main challenge to improving energy efficiency, indoor air quality, and the administration of buildings. Egypt wants to enhance renewable energy generation, decrease greenhouse gas emissions, and improve energy efficiency. Over 40% of overall energy usage is generated by the construction sector (Santamaría et al., 2016). So, the thermal efficiency of the building is crucial for lowering energy use (Miezis et al., 2016). There is a need to explain how energy is utilized in buildings since Egyptian studies indicates that a one-degree rise in outside air temperature over 35 °C increases energy consumption by 100 MW/hour.

1.2. Building insulation for energy efficiency

Insulation is one of several methods that could be implemented to decrease a building's energy usage (Ylmén et al., 2017). Thermal insulation can be described as using materials that have thermal insulating properties that help reduce heat leakage and its transfer from outside the building to inside it in summer and keep the internal temperature in winter. There are three different forms of heat that permeate buildings and are intended to be eliminated by air conditioners in order to maintain the proper temperature. The heat that seeps through ceilings and walls, the heat that enters via the windows, and the heat that is transferred through the natural ventilation openings result in a large increase in the energy demand (Mahmoud, 2022; Mahmoud et al., 2015; Ragab and Abdelrady, 2020).

Building insulation is considered one of the factors affecting the thermal comfort inside the spaces, especially residential ones. On another side, the problem of the energy crisis is being exacerbated by buildings in Egypt. Most of the energy used in buildings is used by HVAC systems, as a result, the best strategy to reduce energy use in buildings is using insulating materials (Ragab et al., 2022). And the heat penetrates the walls and ceilings on summer days at a speed of 60-70% of the heat (Aly et al., 2020). The rest comes from windows and ventilation holes (Abdelhafez et al., 2023). The energy used in the summer to keep the building cool is estimated to be around 66% of all electricity used, hence the importance of thermal insulation to reduce the consumption of energy used for air conditioning purposes, to reduce the temperature leakage through walls and ceilings to achieve an adequate functional housing and reduce cost (Abdelrady et al., 2021). Furthermore, several studies have recently attempted to use waste materials to fabricate building envelope materials with appropriate thermal properties. Studies so far have mostly concentrated on energy conservation in building operations (Abd Elrady and Hassan, 2015), in this regard, industrial and agricultural waste has been widely used to make bricks, mortar, concrete, roofing tiles, and other construction materials (Tarek et al., 2023).

1.3. Building insulation-based industrial waste

Previous studies are divided in terms of the application of materials in construction into several sections, including recycled materials from industrial materials and agricultural materials (Harvey, 2009). This study looks at using industrial waste materials in building construction materials.

1.3.1. Brick

Bricks of several types and production methods were also examined (Tarek et al., 2022; Tarek et al., 2023). Lightweight brick-based fuel waste utilizing oily wastes from the oil and gas industry, porous structures in clay bricks have been created, lowering the bulk density and thermal conductivity of the bricks (Ahmed et al., 2021). Such residues enable the fire temperature to be decreased to safer levels due to their high calorific value (Hajjaji and Khalfaoui, 2009; Limami et al., 2021). Due to their weak adhesion to cementing layers, the glassy phases that form in these remnants render the made bricks useless (Hajjaji and Khalfaoui, 2009). Sludge from wastewater treatment is harmful to the ecosystem when it is dumped in landfills or estuaries. A lack of investment or a valorization law could have financial ramifications for poor sludge management (Limami et al., 2021). By converting recovered sludge from wastewater treatment facilities into eco-friendly, lightweight earth bricks, this issue might be resolved. It is feasible to include different sludge wastes into clay bricks. Clay and water are added to wastewater sludge at a concentration of up to 40%, and the mixture is burned at 1080 °C. When sludge was added, firing shrinkage and water absorption increased (Jahagirdar et al., 2013). Lightweight plastics based on bricks in numerous investigations, different types of foamed polymers have been investigated as potential pore generators in clay bricks. Because they are lightweight and easy to manipulate, plastic materials are employed in a wide range of industries (Limami et al., 2020). Construction and packaging are two of these industries. More than 359 million metric tons of plastic were produced globally in 2018, with 79% of that volume ending up in landfills (Limami et al., 2020). Insulating geopolymer samples were manufactured from clay brick waste, slaked lime waste from acetylene manufacturing, and other waste items. and workshop aluminum waste (El-Naggar et al., 2019). Slaked lime was activated with 0.5% caustic soda. Alum industry waste de-aluminated kaolin was utilized as a binding agent to replace certain clay brick waste. The geopolymer matrix formed pores from hydrogen produced by aluminum and alkalis. Instead of clay brick waste, 5% aluminum trimmings and 15% de-aluminated kaolin increased porosity by over 50%. Light bricks with densities of about 1000 kg.m³. These bricks have 1.4 MPa compressive strength and 0.26 m⁻¹.K⁻¹ thermal conductivity. A geopolymer brick used for insulation should have low bulk density, thermal conductivity, and mechanical strength. Fine clay brick waste, de-aluminated kaolin waste, aluminum trimmings, and wasted slaked lime waste from the acetylene industry are used to make geopolymer bricks.

Philip, et al. (Philip et al., 2019) employed Fly Ash and Bentonite to substitute cement bricks. Geopolymer bricks employ fly ash as a binder and foundry sand as fine aggregate. Bentonite to improve properties, and an alkaline arrangement to finish (a blend of NaOH and Na₂SiO₃). Fly ash with alkalis like NaOH and Na₂SiO₃ produce an alumina-silicate gel with cement-like characteristics that might be utilized as a green binding material. This study's design mix is 0.54:0.44:0.04. Bentonite-fly ash foundry sand the solution-to-fly ash ratio is 0.5, and Na₂SiO₃-to-NaOH is 1.5. Bricks were tested for compressive strength, water absorption, bulk density, soundness, efflorescence, and hardness. This study did not examine thermal characteristics. The created brick has a compressive strength of 6 to 25 MPa, water absorption of 5 to 12%, and is

highly light.

One of the studies waste bricks used as a partial replacement for cement in cement mortar (Naceri and Hamina, 2009). Clinker was swapped out for waste brick in various proportions (0, 5%, 10%, 15%, and 20%) by weight for cement. The physicochemical cement's characteristics in anhydrous and hydrated states, Moreover, the mechanical strengths (flexural and compressive strengths after 7, 28, and 90 days) of the mortar were investigated. The findings demonstrate that the use of artificial pozzolan enhances the mechanical properties of the mortar as well as the cement's grinding and setting times. The mechanical strength of mortar was increased by replacing 10% of the cement with waste brick. However, this study ignores the thermal effect of this cement mortar.

1.3.2. Mortar and cementitious paste

On the other side, an experimental study investigates the feasibility of developing eco-friendly self-compacting cementitious systems for sustainable building construction using wood waste sawdust (SD) (Usman et al., 2018). This study looks to modify the neat Portland cement paste system as a partial replacement of cement, two different gradations of SD, coarse SD (CSD) and fine SD (FSD), were used in various weight fractions of 2%, 5%, and 7%. Using SD in cementitious binders may thus not only promote sustainable development but also result in more durable infrastructures. In this experiment, wood waste consisting of coarse and fine sawdust was successfully used to make self-compacting pastes. used up to 10% as a replacement for cement in the production of cement.

Another study was conducted using Fly Ash as an industrial byproduct by developing a new environmentally friendly compositional mortar that could really reduce CO₂ emissions caused by the exploitation of nonrenewable natural sand and the use of cement in concrete (Gholampour et al., 2021). They entirely replaced cement with glass powder, crushed granulated blast furnace slag, and fly ash as an industrial byproduct, and nonrenewable natural sand with waste-based sands like glass and foundry. The research shows that eco-friendly mortar can be made by using industrial waste as a binder and waste-based sands as fine aggregate.

1.3.3. Roofing tiles

Ceramic roof tiles require significant amounts of clay and energy to sinter (de Azevedo et al., 2020). Thus, geopolymerization, which doesn't involve burning, was used to create a building and construction tile that was more ecologically friendly. With an alkaline solution/ (metakaolin + waste) ratio of 0.26 and curing durations of 7, 28, and 60 days, prismatic specimens were created. For the assessment of technological attributes other than micro stability, such as apparent specific mass, linear shrinkage, water absorption, and mechanical resistance to flexion, precursor ratios of SiO₂/Al₂O₃ were 2.5, 3.0, 3.5, and 4.0. The geopolymerization technique may use glass waste as a precursor, and specimens with a 7-day cure and a SiO₂/Al₂O₃ = 4 ratio are best for civil construction roof tiles. Characterization showed that flat glass lapidating waste may be employed as a precursor in geopolymer materials when mixed with metakaolin. The utilization of this waste enables a new method of utilizing this material, which is generally disposed in landfills, which has environmental benefits and may reduce the economic expenses of this procedure.

Many studies proposed recycling PC and TV waste glass into clay bricks and roof tiles (Dondi et al., 2009). SD's ability to absorb and release water makes it a possible internal curing agent in

self-compacting cementitious materials, making them unsuitable for recycling and making new glass. Clay bricks and roof tiles might utilize this glass. Technological examination of unfired and fired products and laboratory brickmaking process modelling assessed this potential. Recycling funnel and panel glasses into clay bodies decreases mechanical strength and increases sintering during fire. The research overlooked the thermal characteristics of manufactured materials.

According to the literature review, the majority of the attention given to the fabricated previous materials has been on their mechanical characteristics, despite the fact that their thermal properties are extremely vital. While there is a lot of literature on how brick construction impacts the amount of energy required for cooling or heating, roof tiles have gotten comparably less study. This study is primarily concerned with the impact of industrial waste products on thermal insulation. In addition, many of the prior studies have concentrated on insulation for exterior walls. To that end, the literature study does not restrict itself to the topic of roofing tiles but rather investigates the use of industrial waste in the production of exterior materials for building envelopes in general.

The primary objective of this study is to assess the effect of replacing existing roof tiles with proposed thermal tile samples containing varying percentages of crushed aluminum smelting waste CASW on indoor thermal performance, annual energy consumption for cooling purposes, and annual energy savings for social residential buildings in a number of Egyptian cities.

Conclusions were drawn on how could the roofing tile specifications improved to dramatically reduce heat transfer. The regions considered in this study may benefit by considering the recommendations presented in this article. To improve the thermal efficiency of the examined buildings, this study seeks to address the following question: at what firing temperature may the roofing tile best benefit from the addition of 40% CASW to the clay? Does combining this industrial waste with clay have the potential to reduce the amount of energy needed to cool the building?

2. Materials and Method

The study explored the effect of using CASW extracted from the Egyptian Aluminum Company in roofing tiles. The investigation was performed as a new approach to reduce energy required for enhancing thermal conditions in social residential buildings built in various cities without any climatic considerations. In this regard, the study passed through three steps.

In the first step, samples of roof tiles are manufactured, it included collecting the necessary materials and making the necessary preparations. The extraction of thermal characteristics for each roof tile sample constitutes the second step. While the third step is the simulation process which investigated the effect of the proposed tile samples on energy consumption and the internal air temperature of the buildings under consideration. The outcomes of the second step were used as input for the next step. Figure 1 depicts the steps and the framework of the study.

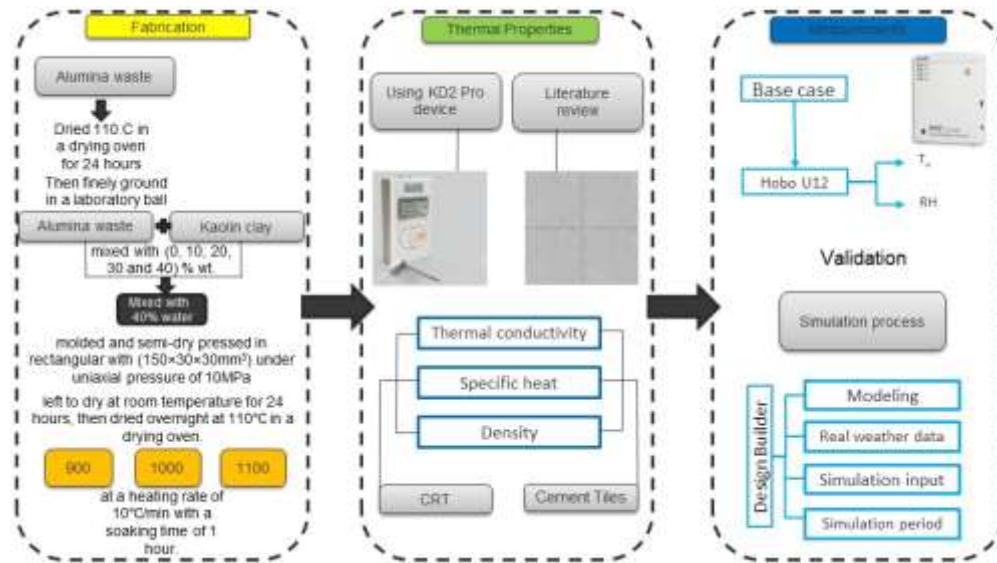


Fig 1. The basic framework of the study.

2.1. Raw materials and roof tiles fabrication

Kaolin clay from the Aswan region of Upper Egypt and CASW freely given by the Egyptian Aluminum Company (Egyptalum), also in Nag Hammadi, were the two types of raw materials used. Alumina waste was dried to 110 °C in a drying oven for 24 hours and was subsequently finely ground in a laboratory ball mill. The waste and clay were mixed with different percentages (0, 10, 20, 30, and 40) % wt. The mixtures were blended with 18% water then molded and semi-dry pressed in rectangular molds with dimensions (150×30×30 mm³) under uniaxial pressure of 10MPa. The samples were left to dry at room temperature for 24 hours, then dried overnight at 110 °C in a drying oven. Samples were then fired in a muffle furnace to different firing temperatures (900°C, 1000 °C, and 1100 °C) at a heating rate of 10 °C/min with a soaking time of 1 hour (Ahmadi et al., 2020). Figure 2 is a diagram depicting the fabrication of thermal roof tiles from industrial slag.



Fig 2. The manufacturing steps.

2.2. Chemical composition of the used raw materials

Chemical analysis of both substances was performed using an x-ray fluorescence spectrometer (AXIOS, panalytical 2005, Wavelength Dispersive WD-XRF Sequential Spectrometer), with the results summarized in table 1.

As can be seen in Table 1, while alumina is the most abundant element in the waste, silica, and alumina make up the bulk of the clay that is put to use.

Table 1. Raw material chemical analysis.

Component	Clay wt%	Waste wt%
Al ₂ O ₃	32.906	64.5
SiO ₂	48.931	2.62
Na ₂ O	0.094	4.29
K ₂ O	0.014	3.61
CaO	0.505	0.47
MgO	0.09	8.31
TiO ₂	5.918	0.13
Fe ₂ O ₃	1.193	0.46
SO ₃	0.291	0.42
F	—	2.24
Cl	0.011	9.82
Cr ₂ O ₃	0.138	0.01
ZrO ₂	0.465	0.034
LOI	9.2	2.74
TOTAL	99.756	99.654

2.3. Thermal characteristics of fabricated roof tiles

Previous studies have shown that substituting 40% of CASW for clay results in products that meet ASTM C-1167 for clay-type roof tile (Ahmadi et al., 2020). where cold water absorption fell to 12%, even below the maximum permissible limit of 15%, the saturation coefficient was 0.83, even below the 0.86 limits, and the obtained breaking strength of 3370N much further exceeded the minimum requirement of 890N.

As a result, all samples with 40% of CASW and with different firing temperatures (900 °C, 1000 °C and 1100 °C) were tested to obtain the thermal properties (Ahmadi et al., 2020). Using a KD2 Pro Thermal Properties Analyzer, which is shown in figure 3. which uses a transient heat conduction technique to digitally record the thermal conductivity, the thermal conductivity of the samples was assessed. The test was carried out in accordance with the ASTM D-5334 standard specification under the following environmental test conditions: (air temperature is 24 °C, and RH is 55%).



Fig 3. KD2 pro device for thermal properties extraction.

2.4. Study Locations and the Model Under investigation

Mainly, Egypt is being located between the coordinates of 22° north latitude and 32° east longitude. According to the Housing and Building Research Centre (HBRC), Egypt has eight distinct geographical climates differentiated by temperature, humidity, and solar heat gains (Ragab, 2020). According to their specific locations, these areas have a diverse set of climates. A model of an actual residential building in seven cities representing Egypt's seven climatic regions was chosen as a case study to be studied in Cairo, Alexandria, Ismailia, Assuit, Hurghada, El-Kharga, and Aswan as shown in Figure 4. The building was chosen for the social housing project because of its low-cost construction techniques. In addition to the government's strategies, which rely on spreading this project across the country without regard for climatic considerations.

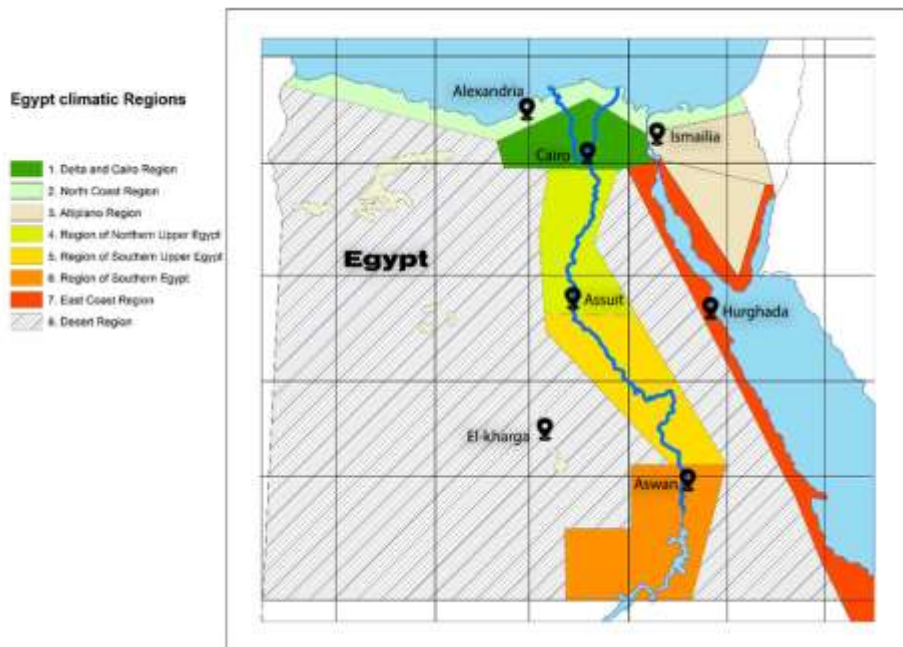


Fig 4. presented the seven cities that have been discussed in the study.

2.5. Modeling and Simulation input data

The simulation software Design Builder was used to create the investigated models. The study's case is a non-isolated building (used in most cities in Egypt's Arab Republic); the building has four similar apartments. The building plan was created in 2D AutoCAD. Then imported into the simulation software as a dxf file. The simulation was conducted mainly to determine the annual energy consumption of cooling. Design Builder was provided with all needed input such as activities, occupancy periods, and equipment according to the traditional Egyptian style (Attia et al., 2012). Other input data as construction and opening were obtained from the project drawings which have been collected from New Urban Community Authority (NUCA). Description of the study building's simulation hypothesis as shown in Table 2.

Table 2. The model input data into the simulation software.

Item	specification
Type	Social residential building
Location	Egypt
Flat area (m ²)	86
Building area (m ²)	357
Number of floors	6
Floor height (m)	3
Occupancy (persons)	5 per apartment
Windows	Single Glazed (SG) 3mm
Window to wall ratio (%)	10
Lighting (Lux)	400
Hvac	4 split air conditioning for each flat
Cooling set-point (°C)	25
Heating set-point (°C)	18

2.6. Model validation

Aswan was chosen as the location for model validation because energy invoices for the research model could be easily obtained monthly from the city. Therefore, different processes have been implemented to verify the model. The first step in the study is to update the Aswan city weather data file that was originally collected using the Design Builder software to reflect the current climatic conditions. In this regard, the 2002 epw file (Energy Plus Weather) for the Aswan climatic zone is included in the simulation software, according to the US Department of Energy's official website. These epw files are text-based CSV files containing hourly data for a full year of meteorological parameter for the study area. However, to mimic a genuine circumstance, the In-situ weather data files have taken the place of the software's existing weather data files for Aswan's weather in 2021 as determined by a meteorological station (Hobo U30), as shown in Figure 5.

Since it was not possible to modify the EPW file of weather data directly, it was first converted to a CSV file to receive various extracted meteorological data from the weather station. Data retrieved from the weather station's input included dry-bulb temperature, relative humidity, and humidity, radiation from the sun, wind direction, and wind speed. while the auxiliary software was used to determine direct radiation and dew point. The altered CSV was exported to a fresh EPW, which served as Design's data input.

After changing those parameters in a fresh CSV, use the builder software. The simulation results were calibrated in accordance with ASHRAE Guideline 14-2002 (Haberl et al., 2005). by simulating the necessary study site factors (such as comfort zone boundaries, heating, ventilation, and air

conditioning (HVAC) system combinations, building materials, and lighting. Comparisons were made using the apartment's third-floor electrical bills. The output of the simulation and actual energy use to depict the average power consumption of the entire building's apartments. The average error of the findings of energy simulation was 10.19% as shown in Figure 6, while the correlation coefficient between the simulated but the actual measured values were 0.995.



Fig 5. The weather station at Aswan University (Hobo U30)

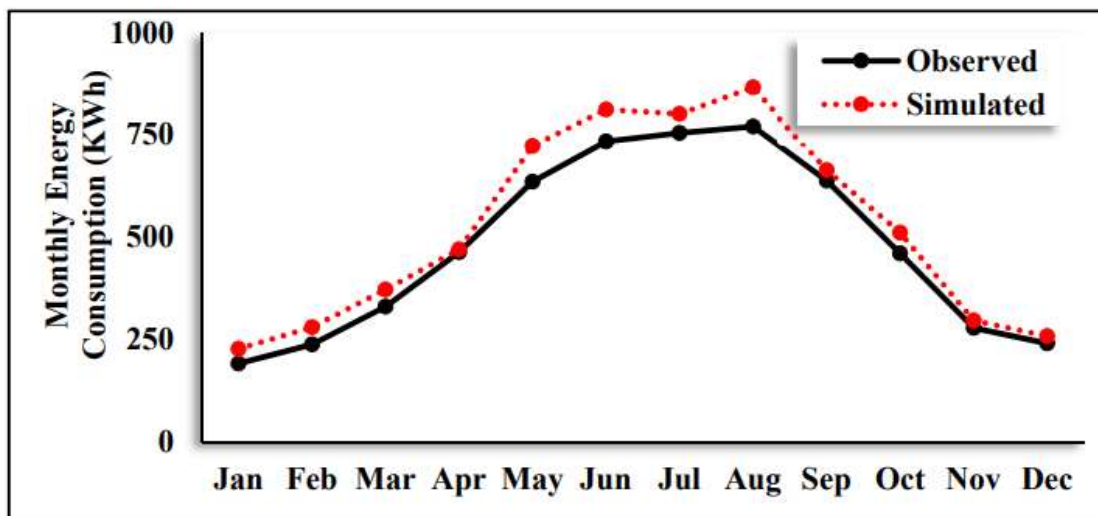


Fig 6. The validation of simulation results.

3. Results and Discussion

This research investigates how different tile samples affect the thermal and energy efficiency of

low-income housing in seven cities spread across seven different climate zones. The thermal efficiency of the most impactful samples in terms of the mechanical strength, and water absorption have been investigated.

Accordingly, tests were conducted to determine the cooling energy requirements of the suggested thermal tile samples fired at 900 °C, 1000 °C, and 1100 °C. Next, this study looks at which of the proposed thermal tile types is best for maintaining comfortable temperatures indoors, both in the summer and the winter. As a result, air conditioners were initially incorporated into the simulation to determine the total amount of energy needed to cool the investigated building model. Subsequently, the building was modelled without air conditioning to assess the thermal efficiency of the suggested thermal tile samples.

3.1. Thermal conductivity of the proposed thermal roofing tiles

Thermal conductivity, specific heat, and density values for manufactured roof tile samples containing 40% CASW are shown in Table 3. The exclusion of industrial waste in the combination of the reference roofing tiles (Base case) resulted in the maximum thermal conductivity 0.84 W/mK. At a firing temperature of 1000 °C, the thermal conductivity of the second roofing tile sample (S2) drops to 0.45 W/mK. Thermal conductivity was measured to be 0.56 W/mK for sample S1, and 0.63 W/mK for sample S3. These results suggest that 1000 °C is the optimal firing temperature when 40% CASW is added to the mixture. The increased density of roofing tiles caused by fire at temperatures over 1000 °C may explain this finding. Roof tiles fired at temperatures less than 1000 °C have a high thermal conductivity and a low percentage of porosity. S1, S2, and S3 all had lower thermal conductivity than the base case by 33.33 %, 46.43 %, and 25 %, respectively.

Table 3. The specification of the investigated roof tiles samples.

Samples	Firing Temperature (°C)	Thermal conductivity W/m. °C	Specific heat J/kg.K	Density (Kg/m ³)
Base case	900	0.84	800	1900
S1	900	0.56	2013	1849
S2	1000	0.45	1800	1769
S3	1100	0.63	1500	1937

3.2. Thermal efficiency of the proposed thermal roofing tiles in the building

It has been determined how well thermal insulation works in the samples of fabricated roof tiles. When air conditioning was switched off, the interior air temperature values of the analyzed building were obtained for the investigated cities in case of utilizing the conventional roof tiles and in case of using the suggested manufactured tiles. The proposed tiles were compared to the conventional roofing tiles (base case) used in climates across Egypt. This study was carried out on the 21st of June. This day is properly known as summer solstice since it is the longest day in the Northern Hemisphere. The findings showed that the internal air temperature varied among the evaluated cities depending on the used roofing tile samples. Figure 7 shows the percentages by which each of the proposed brick samples lowers the internal air temperature relative to the base case sample.

Figure 8 shows that, across all cities, there is a clear improvement between the internal air temperature and the outdoor dry-bulb temperature for the roofing tile samples. With the

exception of Alexandria, where internal air temperatures in the summer did rarely decrease below the outside dry-bulb temperature, the introduction of roof tiles had a noticeable impact on cooling purposes in almost all of the cities studied. The internal air temperatures in Alexandria during the summer season seem to be higher than the outdoor dry-bulb temperature due to the low values of outdoor dry-bulb temperature in Alexandria city during the summer compared to the other studied cities.

Using the proposed roof tile samples in all the investigated models resulted in significantly lower daytime internal air temperatures compared to the base case. The average reduction in internal air temperature for S2 ranged from 0.61 °C to 1.49 °C among the evaluated cities. Aswan had the best outcomes among the studied cities. This means that S2 is best suited to locations with hot, dry conditions. Assuit city's use of S2 was the least effective of all the cities examined, resulting in a reduction of only 0.6 °C. There was a 1.38 °C drop in Cairo, a 0.67 °C drop in Alexandria, a 1.47 °C drop in Ismailia, a 1.11 °C drop in Hurghada, and a 1.45 °C drop in El-kharga. Among the evaluated roofing tiles samples, S3 is the second-most effective, following S2. In the cities we looked at, the average decrease in process temperature was between 0.20 and 1.05 °C.

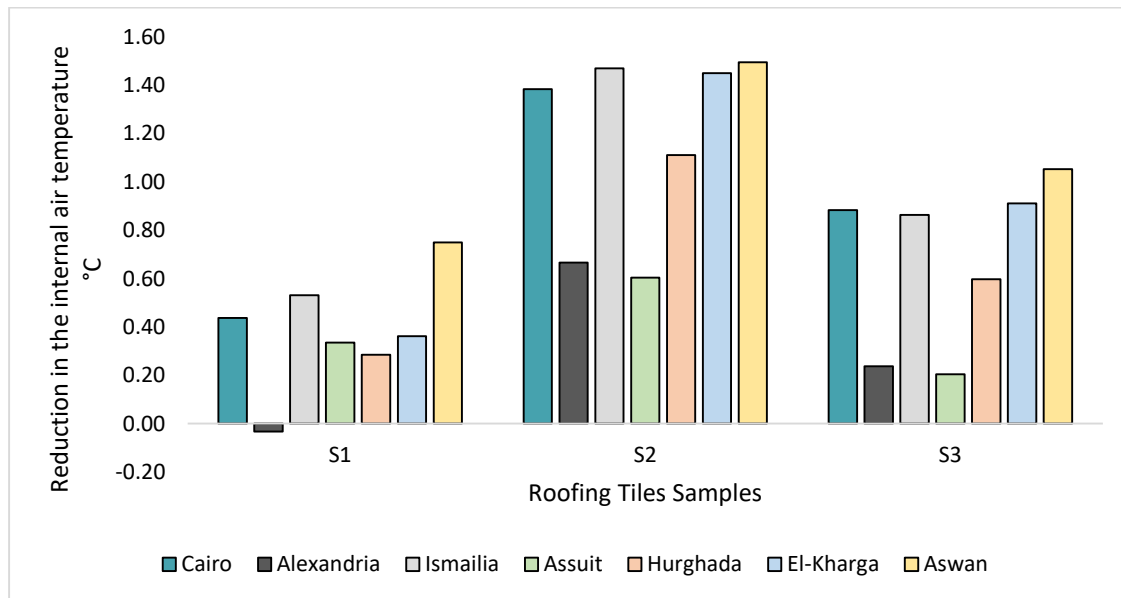


Fig 7. The reduction in terms of internal air temperature for the studied cities.

S1 shows a drop in internal air temperature across all studied cities, averaging out to -0.03°C. Aswan's results were the best of any examined city because the climate there is so hot and dry. Alexandria, on the other hand, had the least effective performance. There was a further drop in temperature of 0.29 °C in Hurghada, 0.33 °C in Assiut, 0.36 °C in Kharga, 0.44 °C in Cairo, and 0.53 °C in Ismailia. Specifically, Aswan, which is hot and dry, performed the best across all three tests. However, the poorest city for temperature reduction varied from sample to sample, with Alexandria in S2 and Assiut in S3 emerging as the worst.

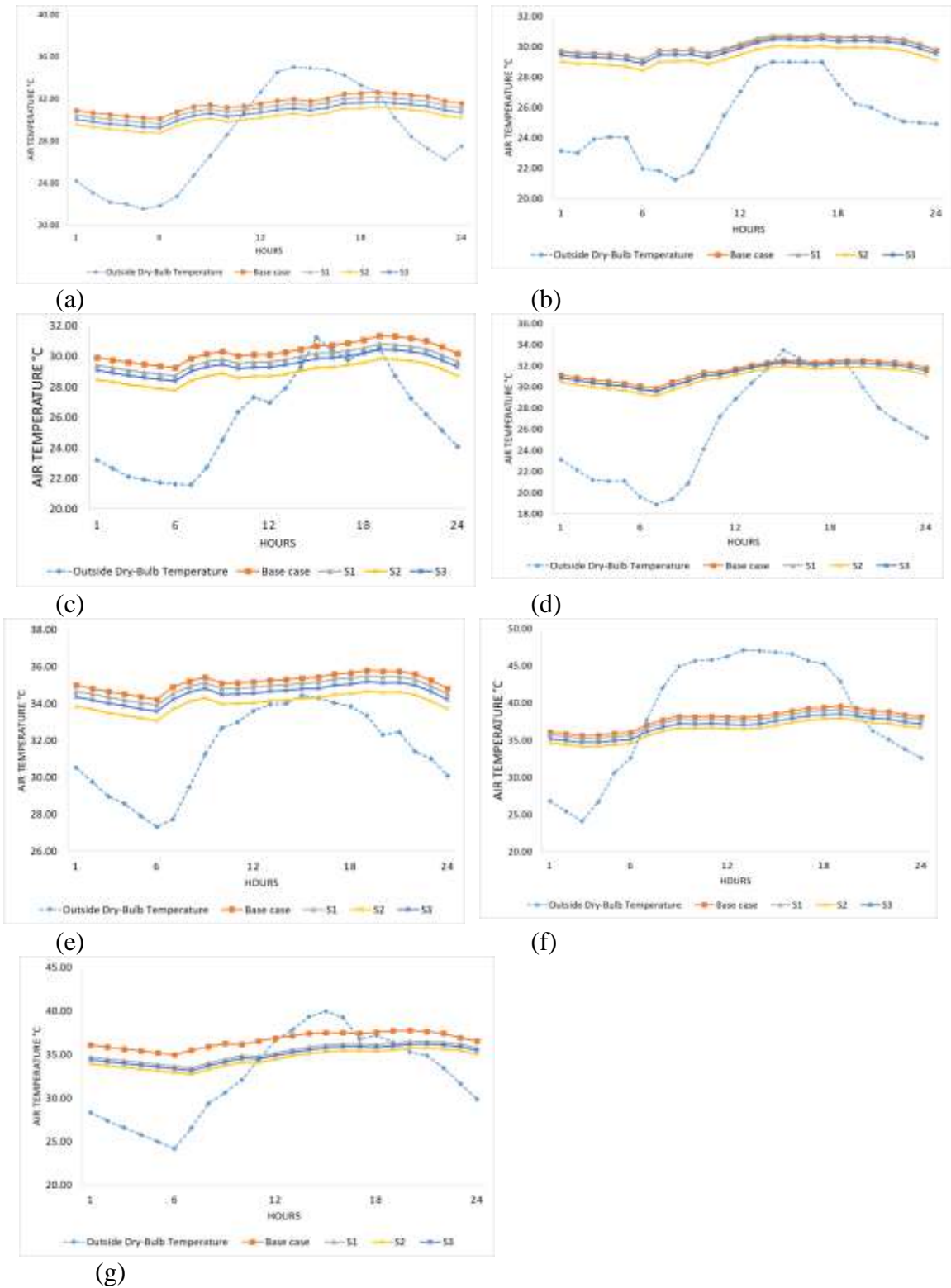


Fig 8. The air temperature and dry bulb air temperature profiles of the proposed samples in the typical summer week for (a) Cairo, (b) Alexandria (c) Ismailia, (d) Assuit, (e) Hurghada, (f) El-Kharga, (g) Aswan.

The thermal conductivities of the samples are shown in Figure 9, as well as the temperature decreases that were achieved in comparison to the base case. The results show that sample S2, which was fired at a temperature of 1000 °C, is the best sample in terms of use in different regions and different climates. The sample had the best results in Aswan, where the temperature reduction was 1.49 °C, while the sample had the worst results in Assuit, where the temperature reduction was 0.61 °C, during the summer.

Aswan once again exhibited the greatest positive effect for S3, with a temperature decrease of 1.05 °C, while Assiut, similar to the case in S2, recorded the lowest reduction of 0.20 °C. Aswan, with its hot and dry environment, prevailed over Alexandria in S3; Alexandria had the worse result, when compared to S2 and S3, respectively.

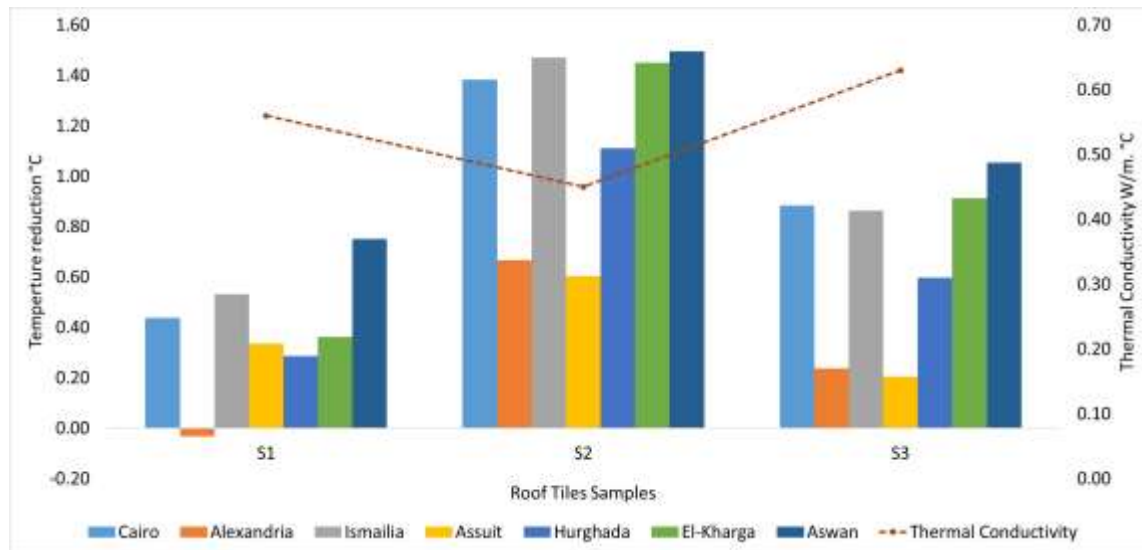
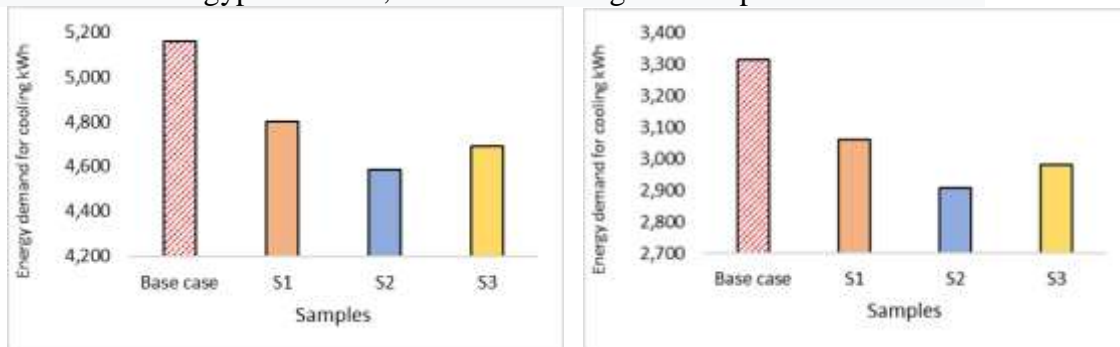


Fig 9. The thermal conductivity and temperature reduction of each investigated sample relative to the base case.

3.3.Evaluation of Energy Needed for Cooling

The findings show that the requirements for cooling energy for the three samples (900 °C, 1000 °C, and 1100 °C) varied considerably depending on the type of roofing material that was used and the characteristics of each climate that was investigated. These differences could be attributed to the fact that the temperatures at which the samples were tested ranged from 900 to 1100 °C. Figure 10 is a representation of the annual energy required for cooling in seven different Egyptian cities, with each having its own particular climate.



(a)

(b)

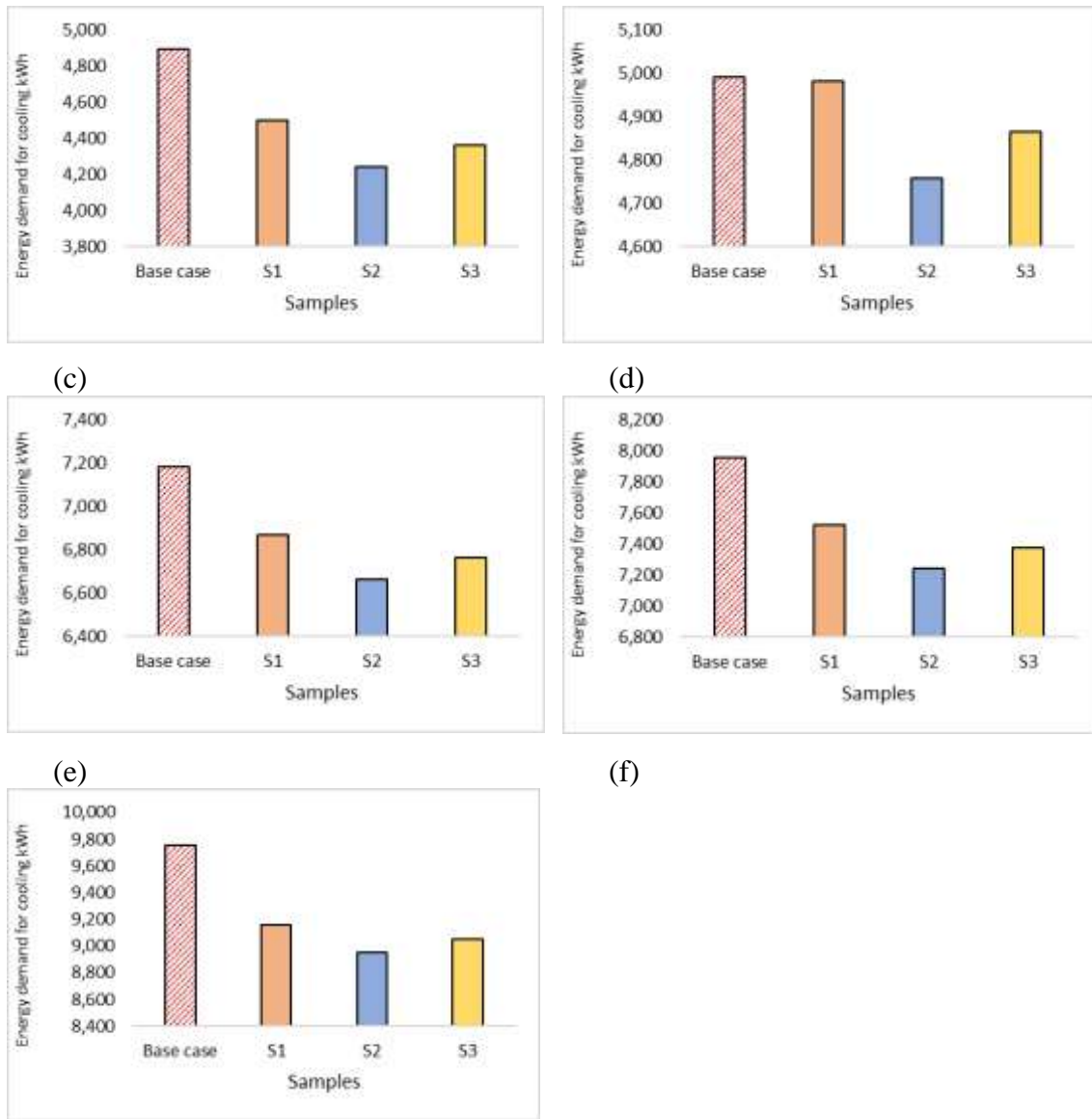


Fig 10. Annual energy demand for cooling for (a) Cairo, (b) Alexandria, and (c) Ismailia, (d) Assuit, (e) Hurghada, (f) El-Kharga, (g) Aswan.

According to the findings of this research, the temperatures in the cities of Aswan, Kharga, Hurghada, Assuit, Cairo, Ismailia, and Alexandria were all lower due to the presence of roof tiles than they would have been without them. The largest proportion of the improvement rate in terms of energy needed for cooling goes to Aswan (8.13%), while the smallest amount goes to Alexandria (12.35%). Roof tiles were fired at 900 °C, 1000 °C, and 1100 °C in order to establish which firing temperature produced the best results. (S2) had the highest performance in every category, as was to be expected due to its lower thermal conductivity in compare with other investigated samples.

In terms of energy needed for cooling, Aswan had an annual energy consumption of 9753.08 KWh in the base case, 9156.29 KWh in the S1 case, 8950.07 KWh in the S2 case, and 9053.09

KWh in the S3 case. Utilization of S2 led to the lowest total annual energy consumption overall. S2 cuts down on the amount of energy used for cooling by 8.23% in comparison to the base case, resulting in a savings of 803.00 kWh.

El-kharga is the next successful city in terms of the reduction in the amount of energy needed for cooling, with a base case consumption of 7961.561 KWh, S1 consumption of 7526.232 KWh, S2 consumption of 7245.647 KWh, and S3 consumption of 7380.288 KWh. As a result, S2 had the lowest overall annual energy consumption. When compared to S1, S2 results in a savings of approximately 8.99% of total energy consumption, which is equivalent to 715.9138 KWh. With a base case energy consumption of 7187.036 KWh, Hurghada ranked third best after El-kharga city in terms of cooling energy purposes; the investigated samples recorded 6868.225 KWh, 6663.586 KWh, and 6766.326 KWh for S1, S2, and S3 respectively. Consequently, considering the improvement rate of 7.28%, S2 is the optimal option among the analyzed samples.

For cooling purposes, Cairo uses less energy than any other city in Egypt, including the Hurghada city. The poorest performance was seen when running the base case, which used 5156.857 KWh of energy. A smaller quantity of cooling energy is needed with some of the other examples compared to the base case. S1 used 4799.28 KWh, S2 used 4585.39 KWh, and S3 used 4688.534 KWh of energy. Comparatively, utilizing S2 in cities showed an 11.08% increase in cooling energy savings compared to the prior city.

Under the most conservative assumptions, the annual energy needed for cooling in Assuit and Ismailia is almost the same. In the base case, the annual cooling energy demand in Assuit is 4991.96 KWh, while in Ismailia it is 4898.099 KWh. While the results of the other samples analyzed vary widely amongst the cities. For illustration, in Assuit, S1 used 4983.46 KWh while in Ismailia, S1 used 4499.27 KWh, for a difference of 484.19 KWh. In the same two cities, S2 used 4757.11 KWh and 4254.36 KWh respectively. However, S3 caused a usage of 4866.92 KWh and 4363.02 KWh in the two cities, respectively.

When it came to the amount of energy that was used for cooling, Alexandria had the best results of any of the cities that were evaluated. However, when it is applied to the samples that were studied, the reduction in energy consumption that it produces is not the best. In each of the four available options (S1, S2, S3, and the base case), the highest annual consumption was 3316.795 KWh. Utilization of S2 led to the lowest total annual energy consumption overall. When compared to the base case, utilizing S2 results in a reduction of 409.679 kWh in cooling energy consumption while simultaneously resulting in an increase of 12.35% in efficiency. That is to say, Alexandria makes approximately half as much progress as Aswan does for every single step forward that is taken in Aswan.

In other words, while the annual energy demand for cooling in the base case stayed the same across all cities, the improvement rates differed greatly as a direct result of using the samples. This was the case even though all cities had the same conditions. The monthly cooling energy required to cool the examined building using S2 roofing tiles throughout the investigated cities is shown in Figure 11. Figure 12 displays the percentage improvement in cooling energy that might be obtained by using the suggested brick samples in the studied buildings.

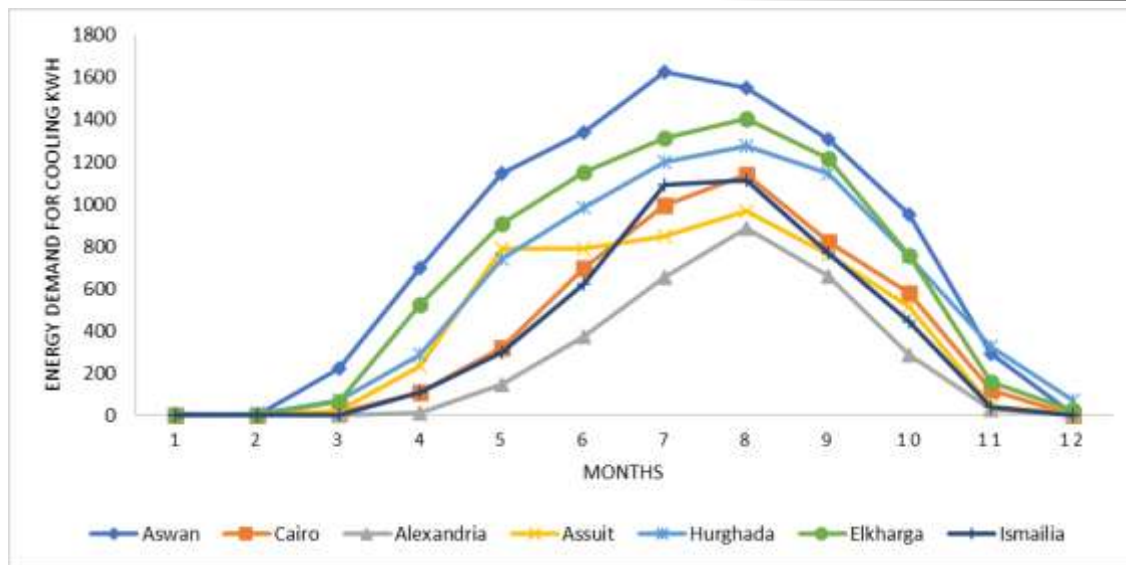


Fig 11. shows the monthly energy required for cooling when S2 tiles were used in the cities that were analyzed.

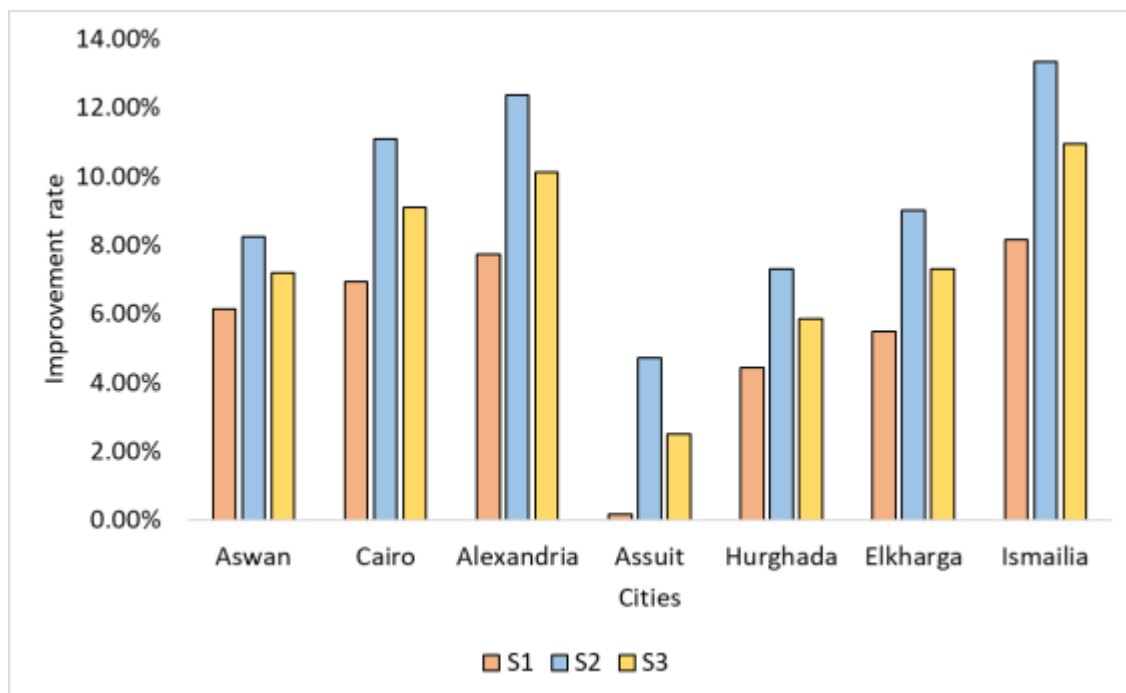


Fig 12. Improvement rate in terms of cooling energy usage.

4. Conclusion and Recommendations

Experiments showed that adding 40% of the clay weight in CASW improved the mechanical characteristics of the resulting fired thermal tiles. Therefore, in this experiment, the effects of varying firing temperatures on the thermal characteristics of roofing tiles prepared by adding 40% CASW to clay were examined. In addition, the impact of combining these industrial wastes with clay on the amount of energy required to cool the building has been investigated. The most noteworthy discoveries of this study are that the thermal conductivity, density, and specific heat

all varied with firing temperature. In particular, S2 fired at 1000 °C had the samples' lowest thermal conductivity value (0.45 W/mK). Across all Egyptian regions, S2 significantly outperformed the other samples in terms of internal thermal performance and cooling energy demands for the examined buildings. A potential annual improvement rate for S2 in lowering cooling energy consumption is between 4.7% and 13.33% across all of the examined regions. Given the widespread distribution of social residential buildings throughout Egyptian cities, this study has the potential to significantly impact the amount of energy required for cooling. However, the results proved that thermal tiles have different performances in relation to the place of their use due to the different regions and the consequent obvious climatic differences .

In conclusion, this study offers an abundance of recommendations for reducing thermal, energy, and overall energy costs. This study, for instance, provides an innovative, effective, and environmentally friendly roofing tile sample consisting of 40% CASW and kaolin clay with a 1000 °C firing temperature. In addition, this study could assist national authorities in enhancing national energy regulations and insulation requirements for building envelopes. In addition, it brings to the attention of the community the necessity of complying with energy code standards during building construction. Furthermore, this work is applicable to other regions with similar characteristics.

The study could be expanded to examine the financial viability of switching from conventional roofing tiles to the proposed manufactured roofing tiles by conducting a life cycle cost analysis.

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