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Design Analysis of a Brick Insulated Mobile Universal Automatic Oven

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Abstract

This study presents the design of a brick-insulated mobile universal automatic oven developed to provide an efficient, portable, and versatile heating system suitable for smoking, drying, and other thermal processing operations. The design considerations were based on geometric configuration, heat transfer requirements, insulation efficiency, and power demand. The oven consists of a main body measuring 1524 × 1524 × 1524 mm, a heating chamber of 1124 × 1124 mm, a chimney of 120 × ϕ50 mm, four tray meshes, and a square chassis frame. The heating system employs two electric microcrystalline non-stick auto-thermostat stoves rated at 2750 W each. Refractory fire bricks were incorporated as insulating materials to minimize heat loss and improve thermal efficiency. The design heat requirement was calculated as 6792.4 kJ with a required power of 4.53 kW, while a recommended operational power of 5.5 kW was adopted for optimum performance. The oven design demonstrates simplicity, durability, adaptability, and operational flexibility, making it suitable for domestic, commercial, laboratory, and small-scale industrial applications. The modular tray arrangement and temperature variability further enhance its multifunctional capability. The study concludes that the developed oven provides improved thermal performance, structural stability, energy efficiency, and operational convenience. Recommendations include the integration of hybrid power backup systems and IoT-based programmable control for smart operation and enhanced reliability.

Keywords: Oven, Design capacity, Design view, Brick insulation, Design analysis.

Introduction

An oven is a thermally insulated enclosure used for heating, baking or drying of a substance. The different types of baking oven are Earth, Ceramic, Gas, Masonry and Electric ovens (Pasqualone, 2018; Lyons & Andrea, 2003). In science and engineering laboratories, it is in form of a small furnace which is used in the removal of moisture from some engineering materials in order to improve their physical properties such as ductility and hardness (Olugbade & Ojo, 2018., Akindele *et al.*, 2017). However, an electric oven has several advantages over other baking ovens. It is easy to install, portable and has a very easy mode of operation, maintenance and high durability (Akinyemi, 2021). Processing of food involves a series of activities embarked upon on both farm produce and livestock to ensure the conversion of food from its raw state to a form that is edible and more appealing for human consumption (Asibeluo *et al.*, 2015; Mondal & Datta, 2008). According to Hager & Morawicki (2013) food processing methods include cooking (boiling), frying, roasting, drying and baking which involve the application of heat from different sources such as burning wood, coal, gas cooker, and electric cooker. Smoking, baking and drying are one of the oldest food processing techniques that is highly sensitive to heat as the quality and selling price of products significantly depend on the heating process (Utazi *et al.,* 2021; Asibeluo, *et al.,* 2015; Chhanwal, & Anandharamakrishnan., 2014). This project is designed to be able to bake, smoke or dry or perform any two of the functions concurrently. It consists of heating chamber insulated with a fire brick to maintain a constant temperature with time within the system. The chassis is designed with an incorporated wheel to enable the mobility of the oven in case the need arises. The entire system is powered electrically with a provision for adjustable temperature for different foods. Conventional air movement is possible through chimney attached to the opening provided at the top body of the oven (Adamu *et al.*, 2021).

Ovens are used in a broad variety of applications ranging from cooking to industrial processing (Kosemani *et al.,* 2021). By considering their energy source they can be broadly classified into two groups, fuel and electric ovens (Ilesanmi & Akinnuli; 2019). Electrical resistance heating has various advantages over systems based on fuel consumption, such as increase in control accuracy and heating speed (Chukwuneke *et al.,* 2018). Thus, electrical heating constitutes a suitable choice for developing laboratory instruments, especially those demanding small volumes and precise temperature control (Ayigun *et al.*, 2022). Electric baking oven has received a considerable attention over the decades, due to its durability, efficiency and availability (Kouemou Hatou *et al.,* 2021). It is a heating chamber,

thermally insulated enclosure, or small which is basically used for the extraction of moisture from some engineering materials to improve their mechanical properties such as hardness and ductility. It can also be used for material processing, heat treatment of engineering materials and sterilization of equipment and instruments for industrial use (Adegbola *et al.*, 2018).

Most conventional ovens for processing of foods (smoking and drying) are mostly powered by charcoal and are adjustable to a specified temperature (Ugwu *et al.,* 2021). These always make their operation to be drudgery and labour consuming. Therefore, the aim of this work is to design a brick insulated mobile universal automatic oven of 1.3 m^3 capacity per single batch. This work would enhance a robust preservation technique for farm and other processed foods that require drying. The drying process would provide dual choice of options for powering the oven to perform its function. Moreover, it would be equipped with mobile wheel which would enhance its mobility including its use for outdoor functions. Its relatively large capacity design of 1.3 m^3 per batch would make it suitability for large commercial farms engaging in livestock processing activities.

METHODOLOGY

The frame structure and chassis formation are designed to be made with angle iron while the heating chamber would be constructed with mild steel and fire bricks. The chamber's wall would be constructed with mild steel lagging with fire bricks as insulator while the tray meshes would be constructed with 2 mm rod wire mesh framed in 20 mm angle iron with roller support for ease loading and unloading. The heating chamber would be of four compartments with total capacity of 1.3 m^3. Drain outlet (chimney) would be made of mild steel coupled at the top center of the oven 1000 mm tall to the atmosphere. The construction work is to be carried out by marking out the plates with specs using scriber, share cutters with drills where applicable. Parts assembly is to be done with fasters while other parts of the machine are to be welded with gauge electrode 10.

The oven was designed to have chassis (which carries the entire weight of the oven), the heating chamber, the power unit which comprises of the power source (grid or fuel) and heating component (electric heater), then the drain outlet. The design was made towards achieving uniform heat distribution; minimizing heat loss using brick insulation; providing automatic temperature regulation; ensuring portability and operational flexibility; and improving fuel/electrical energy efficiency.

DESIGN ANALYSIS

Design consideration for this work includes adequate heating chamber volume; uniform heat circulation; heat resistance and corrosion resistance. Stainless steel is recommended for body formation because of its high strength, good thermal conductivity and resistance to deformation at elevated temperature. Fire brick was considered for insulating material because of its low thermal conductivity, high temperature resistance, durability and thermal shock resistance.

Capacity of the oven

The capacity of the oven is calculated volumetrically since the strength of material is enough to hold the weight of the food to be processed. The capacity is based on the followings:

1. Shape of the proposed oven
2. Size of the standard sheet for the fabrication.
3. The width of the lagging material of the oven.

The shape for this design is cubical while the maximum width of a standard steel sheet available in Nigeria market is 4 ft. (1.22 m). For convenient operation 5 ft. (1.524) m is adopted for this project. The proposed lagging material for the oven is fire brick with a standard width of 0.1 m.

Total volume of the oven (External) $= \mathrm{l}^3$ (1)

$= (1.524)^3$

$= 3.54\ m^3$

where l = external width of the oven

Brick Quantity Estimation for Oven Wall Lagging

The quantity of bricks required for this project depends on the external shape size of the oven.

Net brick required $= \frac{\mathrm{P}}{\mathrm{l_b}} \times \frac{\mathrm{H}}{\mathrm{h_b}} - \sum \mathrm{K}$ (2)

P = Perimeter of the oven

H = height of brick wall (height of the oven)

$\mathrm{l_b}$ = length of brick,

$\mathrm{h_b}$ = height of brick ,

$\sum \mathrm{K}$ = sum of bricks to occupy openings ≈ 0

$\mathrm{P} = 4\mathrm{L} = 4 \times 1524$

$= 6096$ mm

Height of the oven $= 1524$ mm

actual bricks required $= \frac{\mathrm{P}}{\mathrm{l_b}} \times \frac{\mathrm{H}}{\mathrm{h_b}}$ (3)

$= \frac{6096}{200} \times \frac{1524}{100}$

$= 464.52$ bricks $= 465\ bricks$

Allow for 20% reserve,

$bricks\ required = 465 \times \frac{20}{100} + 465 = 558\ bricks$

Actual Capacity of the oven:

$Actual\ capacity\ of\ the\ oven$

= total volume of the oven − volume occupied by the brick wall

volume occupied by the brick wall $= \mathrm{n}(\mathrm{l_b b_b h_b})$ (4)

volume occupied by the brick wall $= 465 \times 0.2 \times 0.1 \times 0.1$

$0.93\ m^3$

Actual capacity of the oven $= 3.54 - 0.93 = 2.61\ m^3$

where:

l_b = length of brick

b_b = width of brick

h_b = height of brick

n = net brick required

Working Capacity of the Oven

The working capacity of the oven is required to ensure adequate conventional heat/air current in the oven. This would allow for fast drying of food after hot smoking. The working capacity is gauged at 50% of the actual capacity therefore:

$Working\ capacity\ of\ the\ oven = \frac{2.61}{2} = 1.3\ m^3$

Heat Design Calculation

Heat transfer (HT) is the transmission of energy from one region to another as a result of temperature gradient. Transmission of heat occurs through three modes: conduction, convection, and radiation. This can occur independently or in combination of modes (Kulla *et al.* (2014). This design made use of 600 ^{0}C (873 K) heating temperature (maximum), 25 ^{0}C (298 K) ambient temperature, higher emissivity of 0.9 (for clay brick wall) and natural coefficient of convective heat transfer of 15 Wm^{2}K.

Mathematically,

$Q = KAdT/dx$ (5)

Where:

Q = the rate of heat flows in Kw (KJ/secs),

dT = temperature difference between the surfaces of metal

$\therefore dT = 873\ K - 298\ K = 575\ K$

dx = thickness of the material (m)= 0.02 m

A = area of the section at right angle through which heat flow (m^2)

$\therefore A = (1.524)^2 = 2.322\ m^2$

K = thermal conductivity of the material (16.2 W/mK for 304 stainless steel)

$\therefore$ From (5),

$$Q = 16.2 \times 2.322 \times \frac{575}{0.02} = 1086.13\ J$$

For convection,

$Q = hA\ (T_a - T_b)$ (6)

Where:

h = coefficient of convective heat transfer (15 Wm^{2}K for natural convection)

A = area of surfaces not perpendicular to direction of heat flow = $2.322\ m^2$

$T_a - T_b$ = temperature difference between the drying surface and the fluid = 575 K

$Q = 15 \times 2.322 \times 15 = 522.45\ J$

For radiation,

$Q = A\varepsilon\sigma(T_s^4 - T_{amb}^4)$ (7)

Where:

Q = heat flux, energy per time,

A = area of heat flux intensity,

σ = Stefan Boltzman constant (5.67×10^{-8} $Wm^{-2}K^{-4}$)

$\varepsilon = \text{emmisivity } (0.9)$

$T_s = \text{surface temperature } (873K)$

$T_{anb} = \text{ambient temperature } (298K)$

$Q = 2.322 \times 0.9 \times 5.67 \times 10^{-8} \times (873^4 - 298^4) = 6789\ J$

Heat Generated in the Oven (Q)

Heat Generated in the Oven Q, is given by the equation;

$Q = mC_p\Delta T$ (8)

Where:

Q = Heat generated

m = Total Mass of wood = 10 kg

Cp= Specific heat capacity of microcrystalline ceramic = 0.8 kJ/kg K with the

Initial oven temperature, T_1 = 25°C (room temperature)

Final oven temperature, T_2 = 600°C

ΔT = Change in temperature

$\Delta T = Final\ temperature\ (T_2) - Initial\ temperature\ (T_1)$

$= 600°C - 25°C = 575°C$

$= 575 + 273 = 848K$

But $Q = mC_p\Delta T$

i. e $Q = 10 \times 0.8 \times 848 = 6784$ kJ

Energy Require in the Oven

$E = \text{Heat generated} + \text{Antivcipated loss}$

$\text{Anticipated loss} = \text{total heat losses} = 1086.13 + 522.45 + 6789 = 8.398$ kJ

$\therefore E = 6784 + 8.398 = 6792.4\ kJ$

Power Required

$\text{Power} = \frac{\text{Energy}}{\text{Time}}$ (9)

The proposed time for full uniform circulation of heat within the oven is 25 min

$\text{Power} = \frac{6792.4}{25 \times 60} = 4.53$ kW

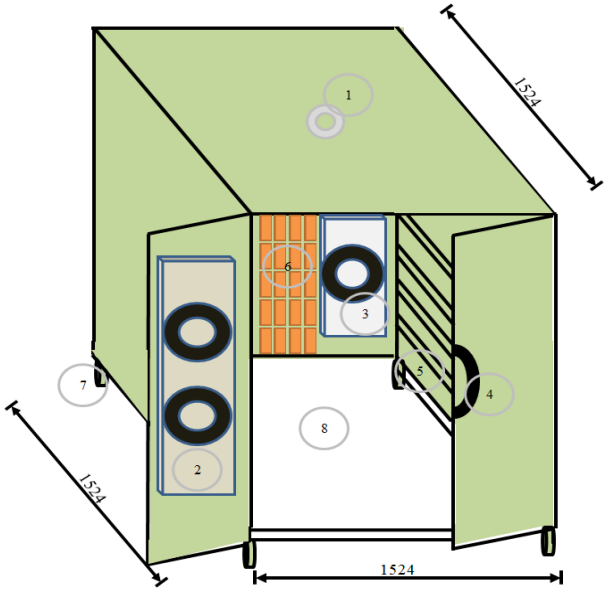
Considering Power factor of safety of 1.2

Power $= Actual\ power \times 1.2$

$= 4.53 \times 1.2 = 5.436\ kW$

Therefore, for this oven, 5500 W power heater is adequate

Design View

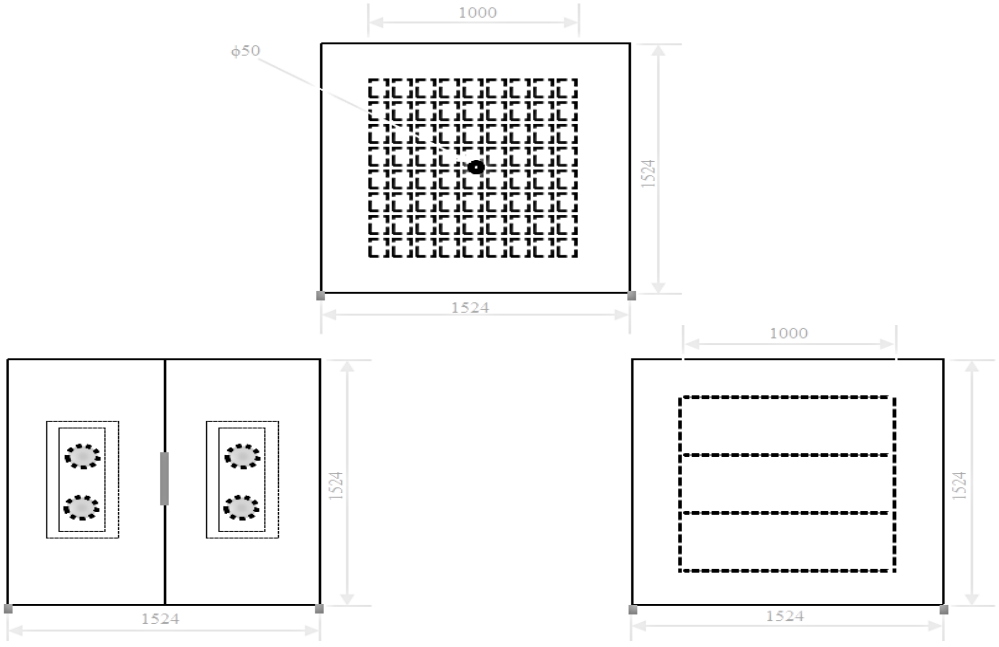


A brick Insulated Mobile Universal Automatic Oven
(Source: Authors' research work, 2026)

LEGEND

1. Chimney pot
2. Front door heater
3. Back door heater
4. Door handle
5. Tray rail
6. Fire brick lagged wall
7. Wheel
8. Concrete floor base

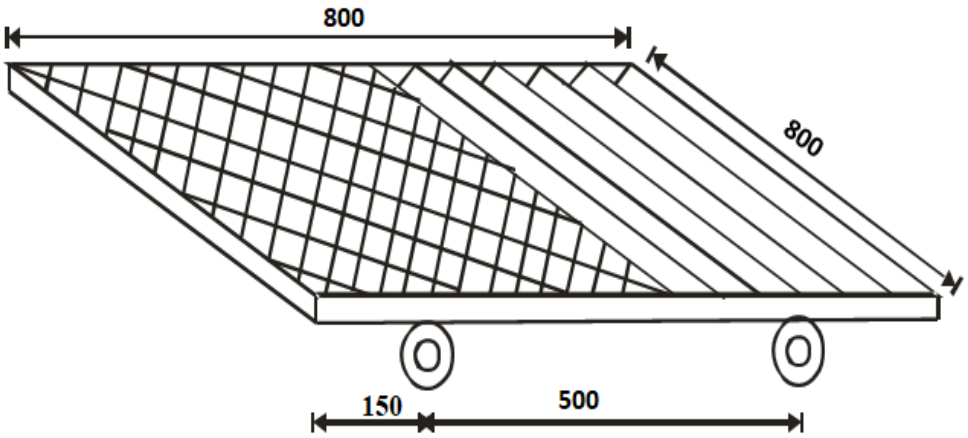
Orthographic Drawings



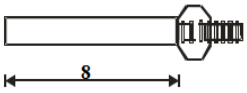
Orthographic View of the A brick Insulated Mobile Universal Automatic Oven

**All dimensions in mm*

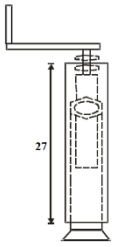
Assembly Drawings



Tray mesh



Tray roller bolt



Chassis Adjustment (Front)

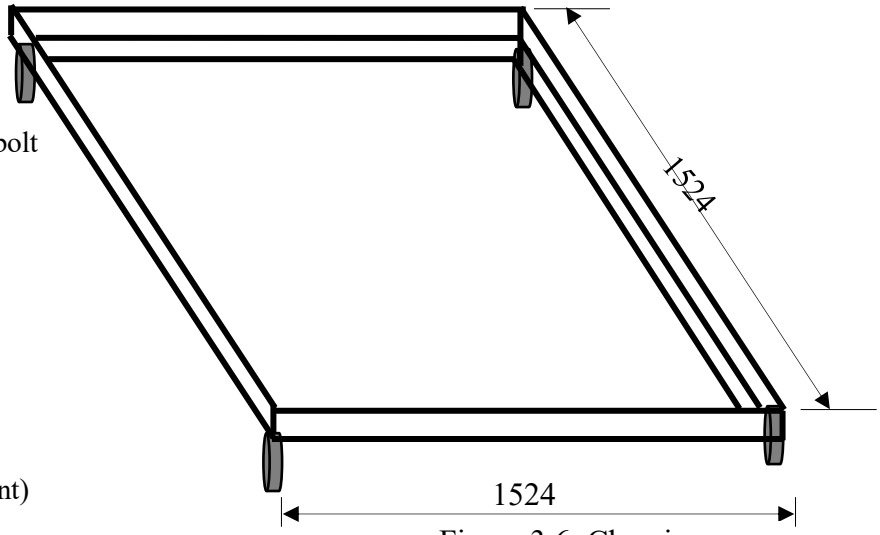
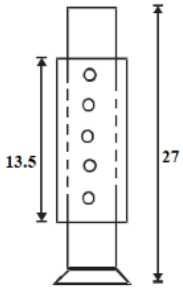
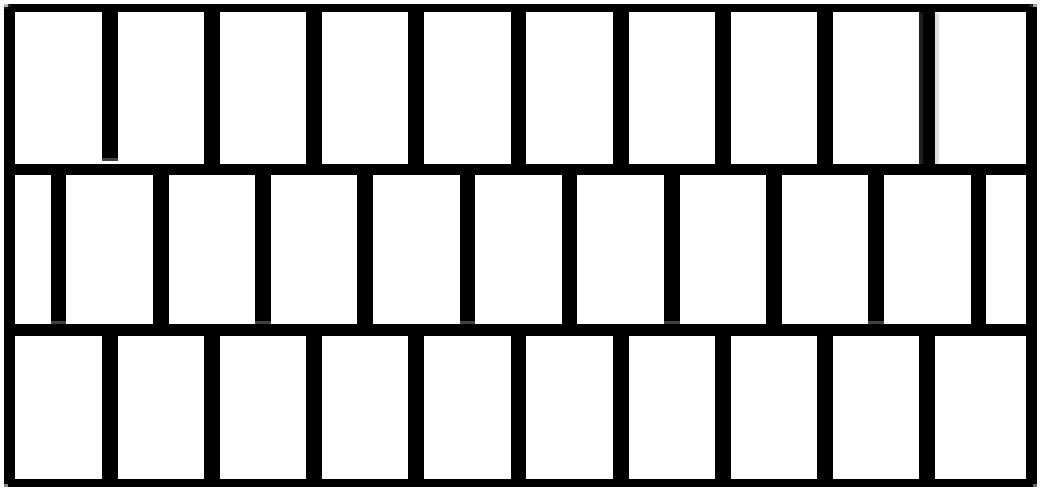


Figure 3.6: Chassis



Chassis Adjustment (Back)

All dimensions in mm



Fire brick Masonry

Design Summary and Components Specifications

The brick-insulated mobile universal automatic oven was designed to achieve efficient heat retention, operational flexibility, and portability for multiple heating applications such as drying and smoking. The design incorporated a cubic main body with dimensions of 1524 × 1524 × 1524 mm and a heating chamber of 1124 × 1124 mm to provide adequate thermal space and product capacity. A chimney measuring 120 × ϕ50 mm was included to facilitate controlled exhaust and airflow regulation during operation. The oven framework consists of a 1530 × 1530 mm square chassis frame designed to provide structural strength and mobility. Four tray meshes measuring 1521 × 1521 mm each were incorporated in a modular arrangement, allowing easy rearrangement and independent usage depending on operational requirements. Heating is provided through a two-phase electric microcrystalline non-stick auto-thermostat stove system rated at 2750 W each, ensuring effective and controlled temperature regulation.

To enhance thermal efficiency, 558 refractory fire bricks of dimensions 200 × 100 mm were designed for lagging materials to reduce heat loss and improve heat conservation within the chamber. The calculated heat requirement for the system was 6792.4 kJ, corresponding to a design power requirement of 4.53 kW, while a 5.5 kW power rating was recommended for optimal operation and performance stability. The overall design emphasizes simplicity, durability, portability, versatility, and adaptability. Its temperature variability enables both low-heat and high-heat operations, making it suitable for commercial and domestic applications. The oven also demonstrates good thermal performance, energy efficiency, structural stability, and operational convenience. Future improvements recommended for the system include the incorporation of hybrid power backup and IoT-enabled monitoring and programmable control systems for smart and automated operation.

The Design summary and components specifications as resulted from the design is given in Table 1

Table 1: Design Summary and Components specs

Component part	Specs
Main body	1524 x 1524 x 1524 (mm)
Heating Chamber	1124 x 1124 (mm)
Chimney	120 x ϕ50 (mm)
Chassis frame (Square)	1530 x 1530 (mm) blade
Tray mesh (x 4)	1521 x 1521 (mm)
Stove (x 2 phase)	Electric, Microcrystalline, Non-stick Auto-thermostat, (2750 X 2 W)
Brick (fire brick) x 558	200 x 100 (mm)
Heat required (Design)	6792.4 kJ
Power Required (Design)	4.53 kW
Power (Recommended)	5.5 kW

(Source: Authors' research work, 2026)

Conclusion and Recommendation

The designed parameters for the oven was based on geometry including size and shape, power required and lagging materials. The design portraited simplicity, portability, durability, versatility and adaptability. Temperature variability for its operations gave the oven capability of changing the task assigned from one form to the other ranging from smoking to drying (low heat task to high heat task). Moderate to high capacity of the design makes the oven adaptable to commercial purpose. The capacity of the oven is in variable ratio by sizing up or down the various components entailed in the design. The tray compartment is modularly designed to be rearrangeable or used independently. The brick-insulated mobile universal automatic oven successfully integrates insulation technology, automation, and mobility into a versatile heating system. The use of refractory brick insulation enhances thermal efficiency by reducing heat loss, while the automatic control system ensures accurate temperature regulation. The design demonstrates good thermal performance, structural stability, energy efficiency, operational convenience and multi-functional applicability. The oven is therefore suitable for domestic, commercial, laboratory, and small-scale industrial applications. A hybrid system designed for an improved power backup; and integrated IoT monitoring and programmable control systems for smart operation are hereby recommended.

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