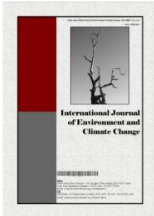

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Experimental Study of Charcoal Savings Achieved by an Insulated Oven with Terracotta Bricks: Implications for the Protection of Forest Resources

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Authors' contributions

This work was carried out in collaboration among all authors. Author SWI designed the study, wrote the protocol and the first draft of the manuscript. Authors GLS and DO performed the experiments. Authors AC and JDB managed the analyses of the study. Author DN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This work is devoted to an experimental study of charcoal savings achieved by an isolated barbecue oven with terracotta bricks compared to the same non-insulated oven. The methodology is based on the simultaneous monitoring of ovens temperatures at the grills level using thermocouples and an infrared imaging camera. The results show that for the same quantity of charcoal used, the temperatures reached in the grill of the insulated oven are above those of the non-insulated oven and the energy losses to the outside environment are very significant in the non-insulated oven. As a result, with a reduction in the amount of charcoal by 35%, the insulated oven achieves the same performance as the non-insulated one. These results highlight the importance of insulating barbecue ovens, particularly with terracotta bricks in reducing of charcoal consumption in Burkina Faso, and consequently in the safeguard of forest resources.

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Keywords: *Barbecue oven; thermal insulation; terracotta bricks; charcoal savings; protection of forest resources.*

1. INTRODUCTION

Biomass is the main energy source for cooking in developing countries [1-3]. In Sub-Saharan African (SSA) countries, the demand for biomass is growing sharply and this trend should continue in the coming decades [4]. Among the different types of wood fuel most used in Africa is charcoal. This resource is widely used in urban areas because of its ease of storage, transportation but also because of its high calorific value and low emission of smoke compared to wood [5].

The social and economic role of charcoal in the fight against poverty in SSA has been emphasized by many authors [6-8]. One of the major drawbacks of this resource is its production. Indeed, charcoal is produced by carbonization of wood. The process is based on the pyrolysis of wood in a controlled environment. The carbonization yield depends on several factors such as the techniques used [9], but also on the quality of the wood [10-12].

In SSA, charcoal production is mainly based on traditional techniques in earthen kilns causing very low efficiency of the order of 13 to 15% [13]. This efficiency indicates that 85 to 87% of wood is lost during the production of charcoal, which has harmful consequences on forest resources. The impact of charcoal production on the degradation of forest resources has been emphasized by many authors [14-17]. Other environmental impacts have also been highlighted by other authors such as greenhouse gas emissions as well as soil degradation [18].

In addition to traditional techniques, improved techniques for charcoal production have been developed around the world [19-21]. Unfortunately, the penetration rate of these technologies in SSA remains low due to several factors including investment costs [22].

In Burkina Faso, charcoal is widely used across the country by households for cooking and water heating or in commercial activities (catering, grilling, foundries, etc.). Between 1992 and 2002, the consumption of charcoal by households in the country increased from 10700 tonnes of oil equivalent (toe) to 133000 toe which represents an increase of more than 12000 toe of charcoal/year [23]. During the same period, the rate of decline in forest resources was estimated at 107626 ha/year [24]. In addition, projections indicate an increase in the consumption of charcoal in the country, from 149.6 thousand tonnes in 2004 to 247.1 thousand tonnes in 2015 [25].

To face this problem, the country has developed various initiatives such as improving forest governance, promoting improved cooking technologies, etc. [26-29]. Unfortunately, in terms of cooking equipment, efforts have mainly focused on domestic cook stoves. Commercial equipment such as ovens (grilling, rotisserie, etc.) remained rudimentary and did not receive any improvement in terms of energy efficiency. Indeed, we have shown in our previous work that non-insulated grilling equipment lost almost half of the energy consumed essentially through the walls [30]. These losses represent a waste of financial resources for the actors but also a waste of forest resources for the country. In order to provide a solution to this problem, we have modeled and simulated an insulated barbecue oven with terracotta bricks. The results obtained show that losses through the walls can be reduced by 60 to 70% [31]. However, the impact of this result on reducing charcoal consumption has not been studied. Also, the main objective of this work is to evaluate the savings in charcoal caused by the use of an oven isolated with terracotta bricks.

2. MATERIALS AND METHODS

2.1 Materials

To carry out the experimental study, the following experimental material was used:

- Two experimental prototype same size ovens: Length = 70 cm, Width = 50 cm and Height = 20 cm. One of the ovens is insulated with terracotta bricks of thickness 4 cm and the other is built only in simple sheet iron of thickness 1.5 mm. For the insulated oven, the bricks are protected from the metal sheet by a wooden frame of thickness 1 cm. The experimental prototypes are shown in Fig. 1.
- Measuring equipment: They consist of K type thermocouples connected to a datalogger (Omega) with precision: 1.5°C,

a balance with precision: ±1 g, and a RAYCAM thermal imaging camera whose uncertainty is around ± 2 °C.

On each grill, three thermocouples record the temperatures, as indicated in Fig. 2.

2.2 Methods

2.2.1 Overconsumption of charcoal in the non-insulated oven

To highlight the overconsumption of charcoal in the non-insulated oven, we have adopted the following method: The two ovens (insulated and non-insulated) are loaded with the same type (same calorific value) and quantity of charcoal, then combustion is started simultaneously in the two ovens. The mass of charcoal used varies from 1.5 to 3 kg usually used by the majority of market players. The thermocouples placed on the grills allow to follow the evolution of the temperature in the of each oven. The simultaneous infrared captures of the ovens, carried out at random, also make it possible to follow the distribution of the temperature field on the outer walls of the ovens. The measurements were repeated three times under the same conditions to have average values.

2.2.2 Charcoal savings in the insulated oven

According to our previous studies [30,31], the energy losses through the walls of non-insulated ovens are of the order of 50% of the fuel consumed. We have also shown that the thermal insulation of these ovens with 4 cm thick terracotta bricks made it possible to reduce these losses by 60 to 70%. If we retain 70%, we obtain a reduction of 35% of the fuel consumed in the insulated oven. To corroborate this hypothesis, we adopt the following approach: We load both ovens with the same type (same calorific value) of charcoal while reducing the amount of charcoal in the insulated oven by 35%. Then the combustion is started simultaneously in the two ovens. Using thermocouples, we monitor the temperatures of the two ovens at the level of the grills. The mass of charcoal used in the non-insulated oven varies from 1.5 to 3 kg. The measurements were repeated three times under the same conditions to have average values.

Fig. 1. Insulated oven (left) and non-insulated oven (right)

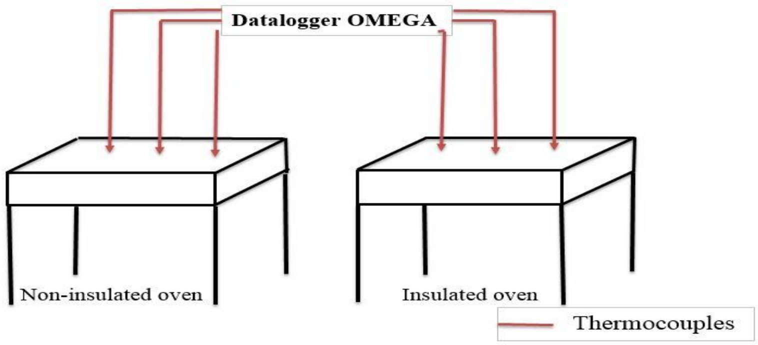

Fig. 2. Experimental setup

3. RESULTS AND DISCUSSION

3.1 Overconsumption of Charcoal in the Non-insulated Oven

Figs. 3, 4, 5 and 6 show the grills temperature evolution of the two ovens respectively for charcoal mass of 3, 2.5, 2 and 1.5 kg.

The evolution of the different temperatures corresponds to the classic profile of the combustion of charcoal in an oven. An initial phase of temperature change is observed due to progressive combustion of the charcoal bed, a peak corresponding to the maximum of charcoal burnt, then a phase of lowering of temperatures indicating the end of combustion. These results also show that for the same quantity of fuel used, the temperatures reached in the grills of the two ovens differ. The temperatures reached for the insulated oven are higher than those of the non-insulated one. The maximum temperatures reached for the insulated oven and the non-insulated one are respectively: For 3 kg of fuel: 204° C and 174° C; for 2.5 kg of fuel : 180° C and 138° C; for 2 kg of fuel : 170° C and 125° C and for 1.5 kg of fuel : 130° C and 110° C. This temperature difference is explained by the fact that in the non-insulated oven, the enormous heat losses through the walls are carried out to the detriment of the energy contained in the combustion chamber, which lowers the grill temperature. On the other hand, the confinement of the heat inside the insulated oven makes it possible to maintain a high temperature in the combustion chamber, and consequently in the grill compared to the non-insulated oven. These results show that to have the same temperature levels reached in the non-insulated oven, the amount of charcoal used in the insulated oven should be reduced. These observations are corroborated by the infrared captures (IFR) below of the two ovens in operation for the particular case where the mass of charcoal is 3 kg.

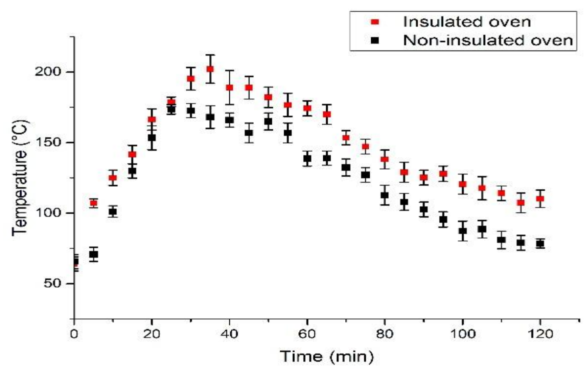

Fig. 3. Grills temperature evolution for 3 kg of charcoal

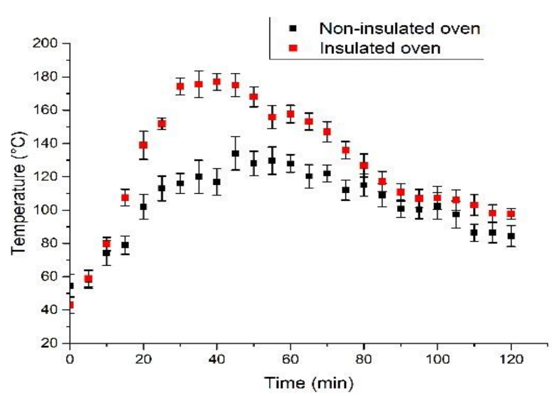

Fig. 4. Grills temperature evolution for 2.5 kg of charcoal

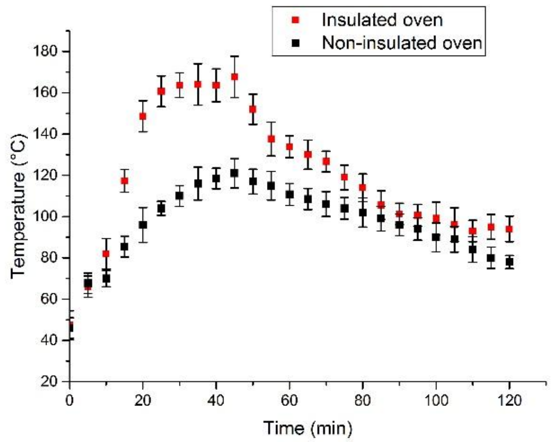

Fig. 5. Grills temperature evolution for 2 kg of charcoal

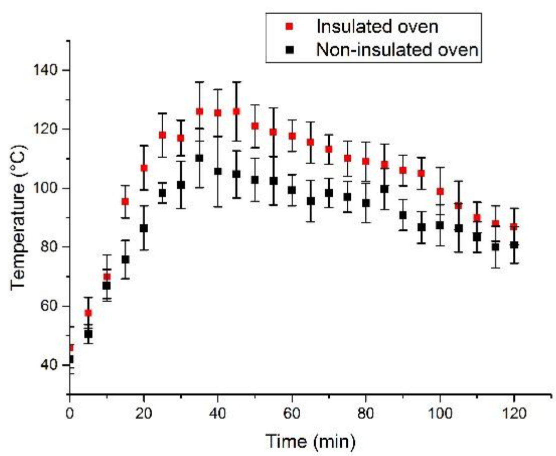

Fig. 6. Grills temperature evolution for 1.5 kg of charcoal

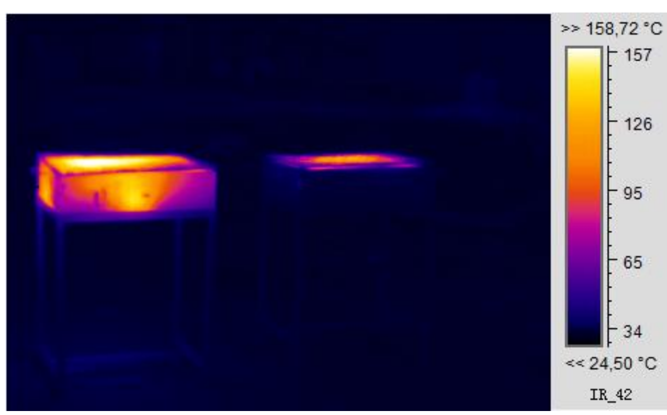

Fig. 7. IFR capture, beginning (5 minutes of the experiment) left: Non-insulated oven, right: insulated oven

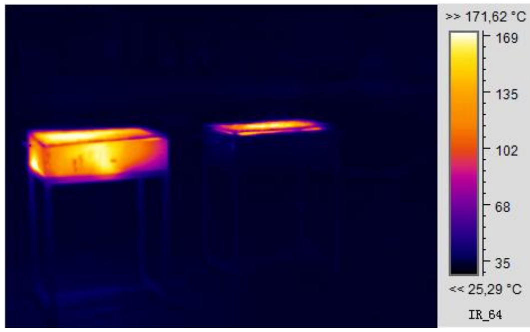

Fig. 8. IFR capture, 25 minutes of the experiment left: Non-insulated oven, right: insulated oven

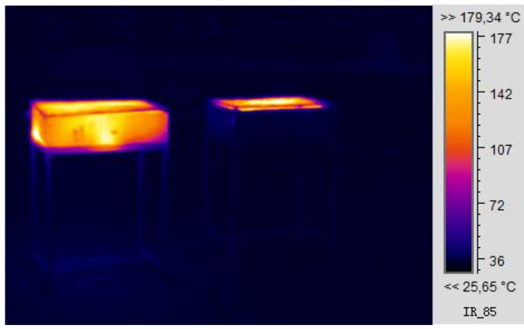

Fig. 9. IFR capture, 50 minutes of the experiment. Left: Non-insulated oven, right: insulated oven

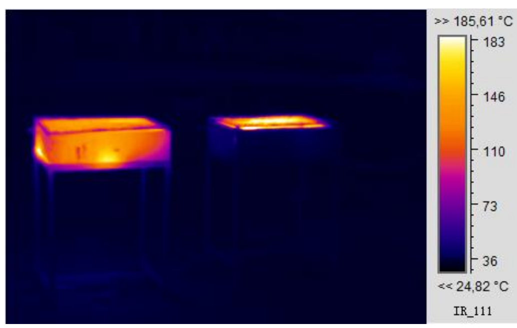

Fig. 10. IFR capture,75 minutes of the experiment left: Non-insulated oven, right: insulated oven

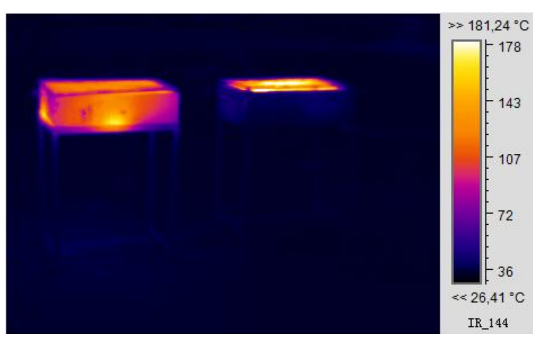

Fig. 11. IFR capture,100 minutes of the experiment left: Non-insulated oven, right: insulated oven

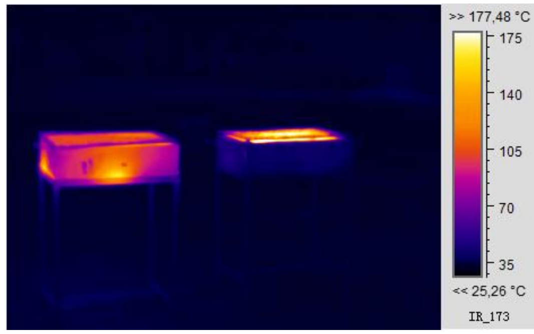

Fig. 12. IFR capture, 120 minutes of the experiment left: Non-insulated oven, right: insulated oven

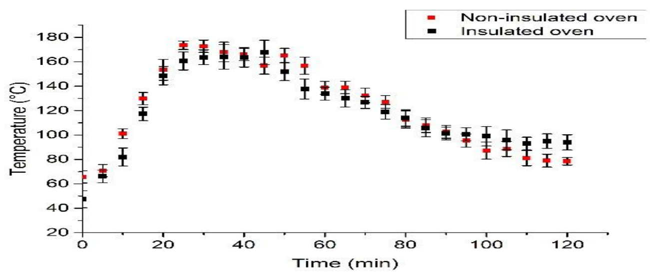

Fig. 13. Grills temperature profiles with 3 kg of charcoal in the non-insulated oven and 1.95 kg of charcoal in the insulated oven

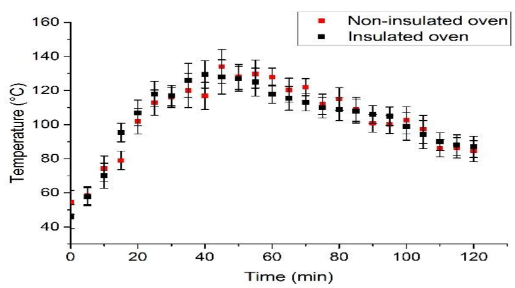

Fig. 14. Grills temperature profiles with 2.5 kg of charcoal in the non-insulated oven and 1.625 kg of charcoal in the insulated oven

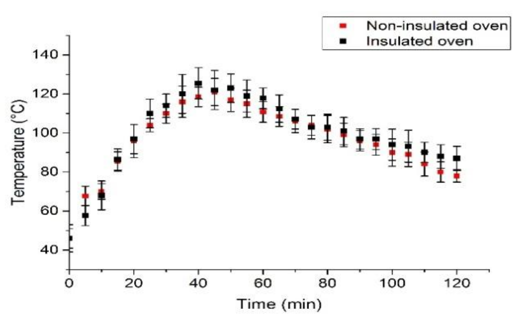

Fig. 15. Grills temperature profiles with 2 kg of charcoal in the non-insulated oven and 1.3 kg of charcoal in the insulated oven

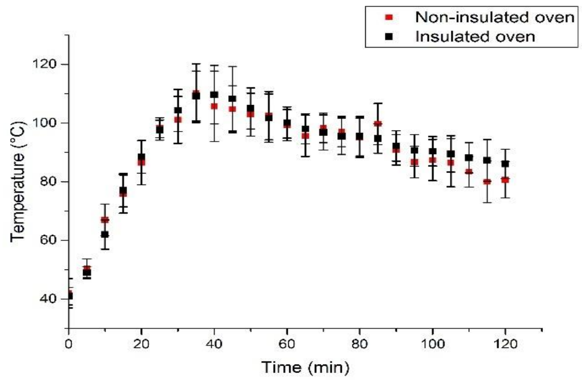

Fig. 16. Grills temperature profiles with 1.5 kg of charcoal in the non-insulated oven and 0.975 kg of charcoal in the insulated oven

As shown in the above captures, the IFR emissions which symbolize the energy losses to the external environment are very important in the case of the non-insulated oven throughout the experiment.

3.2 Charcoal Savings in the Insulated Oven

Figs. 13, 14, 15 and 16 show the grills temperature evolution of the two ovens respectively for charcoal mass of 3, 2.5, 2 and 1.5 kg in the non-insolated oven with a reduction of 35% of the same charcoal amounts in the insulated oven.

The results obtained show that the temperatures obtained in the two oven are almost similar, which indicates that even with a 35% reduction in the quantity of charcoal, the insulated oven achieves the same thermal performance as the non-insulated oven at the level of grills. This result is explained by the fact that in the insulated oven, the reduction of heat losses through the walls brings more energy to the level of the grill, which makes it possible to minimize energy consumption compared to the non-isolated oven.

4. CONCLUSION

In this work, we conducted a comparative experimental study of the performance of two identical ovens, one of which is insulated with terracotta bricks and the other non-insulated. We analyzed the performance of the two ovens in terms of charcoal consumption. The methodology used is based on the simultaneous monitoring of the temperatures of the ovens in operation at the level of the grills using thermocouples and an IFR imaging camera. The results obtained are summarized as follows:

- For the same quantity of charcoal used, the highest temperatures at the grills are those of the insulated oven,
- For the same quantity of charcoal used, the non-insulated oven loses much more energy to the outside environment compared to the insulated oven,
- Even with a 35% reduction in the amount of charcoal, the insulated oven achieves the same performance as the non-insulated oven.

These results show that the use of terracotta bricks in the thermal insulation of barbecue ovens can lead to substantial savings in charcoal, with a positive impact on the forest resources protection.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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