ENERGETIC ANALYSIS OF CLAY OVEN USED FOR BREAD BAKING

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ABSTRACT

Food processing including baking consumes a lot of energy thereby increasing cost of production. Therefore, energy and exergy distribution patterns in clay oven were determined, and computer software to evaluate the energy was developed. Ten clay oven bakeries were used for the study. Sizes, shapes, thicknesses and sources of energy were recorded and temperature taken at an interval of 30min for 7hrs. Energy, exergy and energy losses of the ovens were computed using standard equations. Software was developed using Visual Basic programming language and the performance was evaluated. The ovens were of dome shape, the sizes ranged between 27.40m^2 and 36m^2 and the thickness ranged from 0.19m to 1.11m. Mass of fossil fuel (dry wood) used ranged between 244kg and 270kg as the source of energy. Peak mean temperature of 451 ± 5.6^{o}C was achieved after 180min of heating un-loaded oven. At this temperature, the mean energy, exergy and energy loss recorded were 184.85 ± 8.78MJ, 169.33 ± 7.65MJ and 3.31 ± 1.25MJ respectively. Loading with bread dough reduced the temperature to 153^{o}C after 1hr. The mean energy, exergy ranged between 24.85 ± 0.14MJ and 184.85 ± 8.78MJ and from 15.9 ± 1.86MJ to 169.33 ± 7.65MJ respectively. The mean energy loss ranged between 0.44 ± 0.14MJ and 3.32 ± 1.25MJ. The mean total energy loss was 26.3MJ out of which the door contributed about 26.2MJ (99.5%) of the heat loss. Validation of the software indicated that less than 0.5% marginal error was recorded. The computer software developed served as a useful tool for estimating energy distribution pattern in clay oven.

KEYWORDS: Clay oven, bread baking, energy analysis, computer simulation

1. INTRODUCTION

Bread is a fermented confectionary product produced mainly from wheat flour, water, yeast and salt by a series of process involving mixing, kneading, proofing, shaping and baking . Other ingredients are sugar, milk or fat, which improve the quality of bread. Bread factory at small-scale level produce larger proportion of bread consumed in Nigeria. Baking is a major unit operation in bread making and it has been reported by to consume about 75% of total energy input (Akinoso and Ganiu, 2011). Majority of these bakers adopt clay oven, which uses wood as source of fuel. Clay oven is a thermally insulated chamber used for the heating, baking and drying of food substances. It utilizes high energy in the form of heat. The technology behind clay oven is that it absorbs heat from the fire and then radiates the absorbed heat. The heat absorbed by the wall of the oven flow from region of higher temperature to the region of lower temperature. The heat source is built either within the oven itself (a black or Roman oven) or in a firebox that vents into the oven (a white oven); smoke is vented through the front of the oven, either directly to the outside or through a chimney immediately above the oven door. The oven comes in different sizes and forms, depending on its usage, either commercial or subsistence, although, both use the same technology.

Energy and foods are concern of developing countries, because chains of food production consume a lot of energy (Wang, 2009). Energy efficiency is a fundamental element towards a sustainable food and energy development. Therefore, improvement on energy generation, estimation and conservation is important for development of industries. Although some studies have been conducted that explore the multifaceted sources and uses of energy in agriculture at the farm level, there are however currently few studies on energy use for further downstream in the food chain especially in food processing, packaging, storage, and distribution (Ziesemer, 2007). Few of the processing factories have little precise idea of the energy consumption of different production areas and in the absence of detailed internal monitoring, the energy efficiencies of different operations is also usually unknown (Jekayinfa and Olajide, 2007). Research reports on energy consumption and conservation patterns in Nigeria include rice processing (Ezeike, 1981), beverage industry (Akinbami *et al.,* 2001), and palm kernel oil processing (Jekayinfa and Bamgboye, 2004). Energy expenditure on sugar processing (Abubakar et al., 2010), bread baking (Akinoso and Ganiu, 2011) and *gari* (Akinoso and Kasali, 2012) have been reported.

The use of energy as a measure for understanding and improving the efficiencies of energy systems can be misleading and confusing (Marc et al., 2009). Therefore, it is important to understand the concept and component of energy for proper analysis. This must be made through the energy quantity as well as the quality. Exergy, which is based on the second law of thermodynamic analyses energy on quantity as well as the quality. It identifies the magnitudes and the locations of real energy losses, in order to improve the existing systems, processes or components (Ganapathy et al., 2009). It also can be used to assess and improve the efficiencies of energy systems, and can help better understand the losses in energy systems by providing more useful and meaningful information than energy provides. Exergy analysis is a methodology that uses the conservation of energy principle (embodied in the first law of thermodynamics) together with non-conservation of entropy principle (embodied in the second law) for the analysis, design and improvement of energy and other systems (Marc et al., 2009). The exergy method is useful for improving the energy efficiency, for it quantifies the locations, types and magnitudes of wastes and losses. This analysis identifies the margin available to design more efficient energy systems by reducing inefficiencies. Operations of food processing equipments require energy and inefficient energy utilization hike cost of production, and clay is one the major mineral deposit in Nigeria (RMRDC, 1990; Omowumi, 2001).

The objective of this study was to analyze energy and exergy distribution patterns in clay oven used for bread baking.

2. MATERIAL AND METHODS

2.1 Parametric Data

Shapes, thickness, size, quantity of wood used in baking and temperature gradient at 30 minutes interval for 7 hours of ten clay ovens use for bread baking in Ibadan Nigeria were measured. Capacity of the ovens for bread baking was also recorded.

2.2 Energy Analysis

Heat generated, heat loss, energy and exergy efficiencies of the clay ovens were calculated using standard equations (Equations 1 to 8).

$$Q = mC_p(T_1 - T_0) \quad (1)$$

$$E_{xi} = Q(1 - \frac{T_0}{T_1}) \quad (2)$$

$$Q_L = \frac{kA}{x}(T_1 - T_0) \quad (3)$$

$$Q_c = \frac{A}{A_T} * Q_w \quad (4)$$

$$Q_{TL} = (Q_L) + (Q_c) \quad (5)$$

$$q = Q_G - Q_{TL} \quad (6)$$

$$Energy\ efficiency = \frac{enegy\ output}{exergy\ input} \quad (7)$$

$$Exergy\ efficiency = \frac{exegy\ output}{exergy\ input} \quad (8)$$

Where Q = quantity of energy generated (MJ); E_{xi} = exergy input (MJ); T_o = reference temperature (ambient); T_1 = highest temperature (°C); m = weight of firewood (kg); C_p= specific heat capacity of wood (kJ/kg k); Q_L = Quantity of heat loss by conduction (kJ); K = Thermal Conductivity of the clay (W/mk); X = Thickness of the Clay oven (m); A = Dimensional area of the oven (m^2); Q_c = quantity of heat loss by convection (MJ); Q_w = Total heat generated by wood (MJ/kg); h = convective heat transfer coefficient ($W/m^{2o}C$); A = area (m^2); A_T = Total area of clay oven (m^2); Q_{TL}= total heat loss (MJ); q = Effective heat; Q_G = heat generated; Q_{TL} = Total Heat loss

2.3 Software Development

The software package was developed using Visual Basic. Data obtained from energy analysis was used as a platform on which the event programme was structured. Highlighted programme algorithm was used.

1. Start program.
2. Select type of computation to perform. Either 'Exergy' computation or 'Mass of wood' computation.
3. Input variables C, To, K, T, Tf, Tw, A', A'',A'''.
4. Compute wall surface area excluding door, A'=A'-A'''
5. Compute total, T'=A'+A''+A'''
6. If selection type="Exergy" then input M else input E then goto 13
7. Compute total energy, Etotal=MC(T-To)
8. Compute energy loss (wall), Ew=(KA'(T-To)/Tw), energy loss(floor), Ef=(KA''(T-To)/Tf), energy loss(door), Ed=(A'''/T')E
9. Computer total energy loss, Eloss=Ew+Ef+Ed
10. Compute effective energy, Eeff=Etotal-Eloss
11. Compute exergy, E=Eeff(1-(To/T))
12. Display E and goto 17
13. Compute effective energy=(E-T)/(T-To)
14. Compute Etotal=(Eeff+Ew+Ef)/(1-(A'''/T'))
15. Compute M=Etotal/(C(T-To))
16. Display M
17. Display Ew, Ef, Ed, Eloss, Etotal, Eeff
18. End program.

3. RESULTS AND DISCUSSION

3.1 Parametric Data of Clay Oven

Each oven was used to bake bread dough produced from 300 kg wheat flour. The result obtained for the ten clay ovens A - J showed that they were of dome shape, with oven A to H having a circular-like shape floor and oven I and J, a rectangular shape floor. The areas of the wall showed that oven A, B and I have the same value of 22.1m^2, for oven C, D, E, F, G, H, and J the corresponding areas are 22.4m^2, 26.8m^2, 25.1m^2, 26.2m^2, 20.4m^2, 20.3m^2 and 23.5m^2 respectively. Ovens A and B have the same floor area of 9.60m^2, likewise oven D and J with value 9.10m^2 and oven H and I with value 9.00m^2. Oven C, E, F and G floor areas were 8.20m^2, 10.90m^2, 8.00m^2 and 7.00m^2 respectively. The value of door areas showed that 0.44m^2 was recorded for oven C and D, 0.40m^2 was recorded for F and G, and 0.68m^2, 0.64m^2, 1.20m^2, 0.50m^2, 0.48m^2, 0.42m^2 for oven A, B, E, H, I and J respectively. Thickness of wall oven A, B, E, F, I and J have the same value of 0.2m, oven C and D recorded 0.19m and oven G with a value of 0.22m. Floor heights of oven E and H have the same value of 0.90m, oven F and I with value 0.95m and 0.60m, 0.50m, 0.45m, 0.85m, 1.11m, and 0.48m for oven A, B, C, D, G, and J respectively.

3.2 Source of Heat Energy

Dry wood was used to heat the ovens. Recorded masses of dry wood used for baking 300kg of wheat flour dough to bread showed that oven A and B consumed 265kg of dry wood, oven E and F consumed 260kg of dry wood, and for oven C, D, G, H, I, and J, the values of dry wood consumed were 268kg, 262kg, 250kg, 240kg, 270kg and 244kg respectively. The lowest mass of dry wood was 244kg and the highest mass was 270kg.

3.3 Temperature Distribution

The result of heat energy generated from the dry wood showed that energy increases steadily with duration (Figure 1). As expected, oven temperatures increased with heating period. From ambient temperature of 30±2°C, temperature of the oven chambers rose to 120°C in the first 30 min. of heating for all the ovens except oven F and G which recorded temperatures of 130°C, and oven A with 110°C. Loading with bread dough reduced the temperature to 153°C after 1hr. The peak heat energy generated was achieved after 180min of heating un-loaded ovens and the peak temperature ranged between 440°C and 460°C. Oven B recorded the highest temperature of 460 °C, clay oven G recorded the lowest temperature of 440°C in 180min (Table 1).

3.4 Heat Loss

Three media of heat loss to the environment were noticed. Heat was lost through the walls, floor and door of the oven. In the first 3hrs, it was observed that heat loss in the clay oven increased steadily up to a peak value before decrease. Peak heat energy loss value recorded for door were 3.97MJ, 3.82MJ, 4.24MJ, 2.26MJ, 6.07MJ, 3.06MJ, 2.01MJ, 2.47MJ, 2.97MJ, and 2.22MJ for oven A, B, C, D, E, F, G, H, I and J ovens respectively. The peak energy loss through the wall of ovens A, B, C, D, E, F, G, H, I and J respectively were 12337.50J, 11602.50J, 11878.75J, 12526.32J, 14810.53J, 13365.75J, 13427.50J, 9736.36J, 11165J, 11740.63J. While floor energy lost were 1990.63J, 1680.00J, 2054.40J, 2266.67J, 1124.12J, 1289.83J, 863.16J, 662.16J, 1045J, 1006.58J for A, B, C, D, E, F, G, H, I and J ovens. The highest heat loss was observed at the door of the clay ovens, this was associated to opening of door during heating and construction of the door with mild steel of high thermal conductivity of about 48.5W/mK..

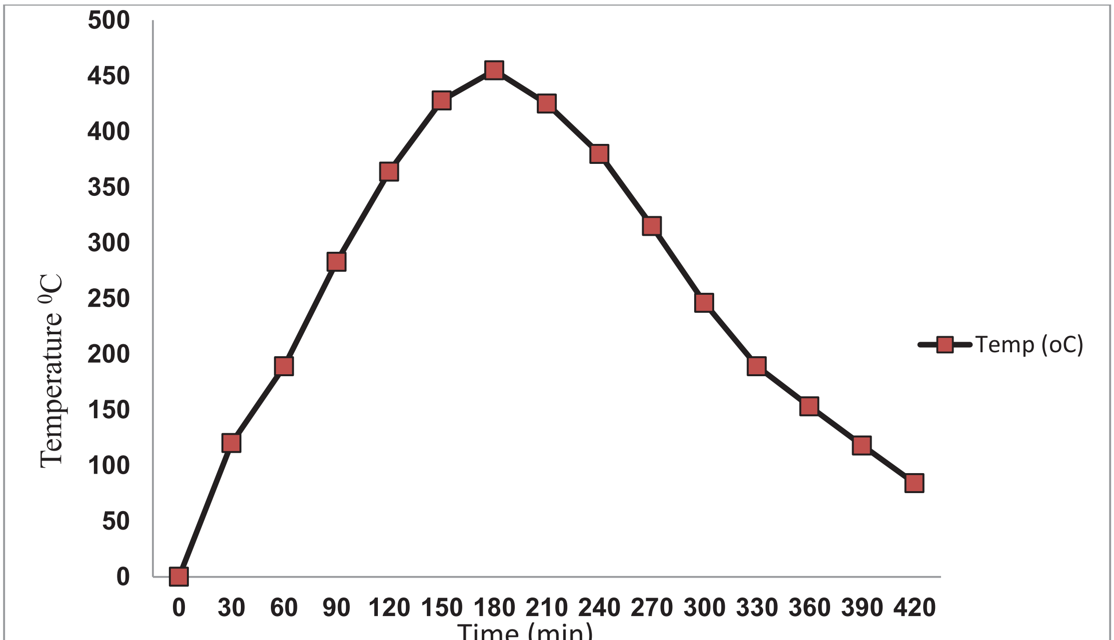

Figure 1. Plot of temperature against time

Table 1. Heating temperatures of the ovens during baking

Time (min)	**Oven A °C**	**Oven B °C**	**Oven C °C**	**Oven D °C**	**Oven E °C**	**Oven F °C**	**Oven G °C**	**Oven H °C**	**Oven I °C**	**Oven J °C**
0	30	30	32	30	30	29	30	30	32	30
30	120	110	120	120	120	121	130	120	130	120
60	190	185	188	190	185	200	200	185	178	189
90	290	250	290	290	280	280	280	280	290	300
120	380	320	350	380	380	360	375	360	345	360
150	440	400	420	440	440	440	425	400	400	430
180	450	450	460	455	450	455	440	450	445	455
210	415	430	435	425	420	420	410	420	450	435
240	370	390	395	380	360	380	360	360	420	380
270	300	340	305	340	300	330	290	300	340	305
300	240	270	235	250	240	300	225	240	280	235
330	182	240	150	200	180	170	180	180	230	180
360	155	185	120	155	150	155	155	150	150	152
390	120	130	100	130	110	125	120	120	105	120
420	90	90	85	90	90	80	85	90	80	89

3.5 Thermal Efficiency of the Ovens

Each oven was used to bake bread dough produced from 300 kg wheat flour. Actual energy utilized for bread baking increased progressively with time in the entire clay oven up to a peak point before it began to decline (Figure 2). The peak time recorded for clay oven A – J was 180min and the corresponding percentage values are 91.37%, 91.20%, 91.35%, 92.20% 92.14% 90.60% 92.10% 91.98% 91.25% 91.98% respectively (Table 2). High efficiency might be associated with low thermal conductivity of clay as reported by (Folaranmi, 2009). The least efficiency (58.99% to 65.85%) were recorded after 420min of heating. At 300min, percentage of actual energy utilized across the clay ovens for baking were recorded which ranged from 84.67% to 87.41%. It also showed the ability of clay oven to hold heat as reported by (Forno, 2012) that thermal mass and insulation are the two primary characteristics that describe an oven's ability to absorb and hold heat, and make it useful for cooking. The thermal conductivity of clay, which is the property of a material that indicates its ability to conduct heat, is mostly controlled by water content and other properties (Kromer and Mörtel 1988). It ranges between 0.25 to 2.0 W/mK.

The small difference in the efficiencies is because the specific chemical exergy of firewood is slightly greater than its specific base enthalpy. The lower value for exergy efficiency shows that even if some energy is associated with the firewood, this part of energy becomes less available in reality. Exergy efficiency is a measure of how near a process approaches ideality and a measure of how near energy transfer approaches ideal transfer.

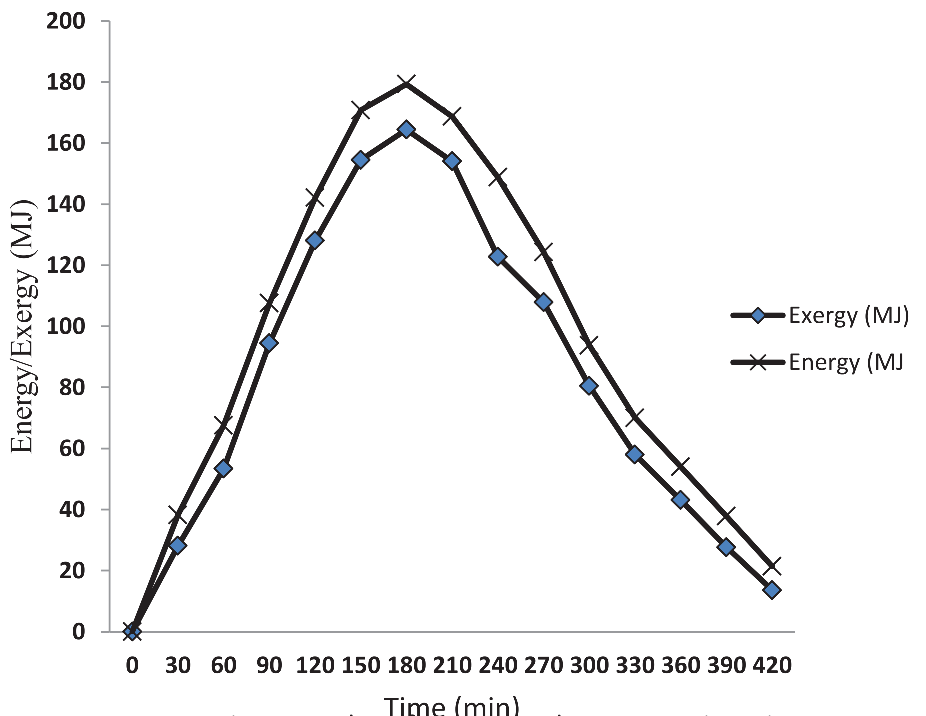

Figure 2. Plot of energy and exergy against time

Table 2. Energy efficiencies of the ovens during baking

Time (min)	Oven A %	Oven B %	Oven C %	Oven D %	Oven E %	Oven F %	Oven G %	Oven H %	Oven I %	Oven J %
0	-	-	-	-	-	-	-	-	-	-
30	74.04	71.19	71.88	73.35	74.09	73.57	76.03	73.92	74.11	73.86
60	83.13	82.02	81.33	82.36	82.76	82.74	82.74	82.57	80.64	82.84
90	88.51	86.15	87.20	87.68	88.20	86.74	88.25	88.00	87.47	90.27
120	90.93	88.72	89.05	90.08	90.98	88.97	90.93	90.34	89.20	91.60
150	91.99	90.55	90.55	91.13	92.05	90.39	91.86	91.16	90.45	91.98
180	92.14	91.37	91.20	91.35	92.20	90.60	92.10	91.98	91.25	91.98
210	91.58	91.06	90.80	90.90	91.72	90.08	91.60	91.52	91.32	91.68
240	90.72	90.36	90.07	90.08	90.55	89.38	90.60	90.34	90.82	90.70
270	88.85	89.26	87.73	89.17	88.90	88.26	88.61	88.70	89.06	88.79
300	86.38	87.02	84.67	86.07	86.43	87.41	85.66	86.24	87.08	85.90
330	82.45	85.66	77.10	83.13	82.32	80.26	82.36	82.13	84.64	82.06
360	79.61	82.02	71.88	78.87	79.02	78.66	79.71	78.84	77.34	79.04
390	74.04	75.30	66.65	75.23	71.84	74.32	74.13	73.92	68.35	73.86
420	65.81	65.26	61.11	65.20	65.85	61.69	63.95	65.70	58.99	65.28

3.6 Software Application

The data collected from different oven was used to validate the software. The result showed that less than 0.5% marginal error was recorded. The exergy software calculator is a screen-oriented programme that can be used to estimate energy distribution pattern obtainable from a known mass of firewood in clay oven with respect to its dimension. Figure 4 show the flowchart on how the programme was run to achieve results. Figure 3 show the graphical user interface used to execute the events programme respectively. The graphical user interface is the platform by which input variables data were captured into the text boxes provided for the user before the computer system could run. The graphical user interface was divided into six sections. The first section has an option button showing exergy and mass of wood depending on the subject of interest; the buttons that correspond will be click. The second section is the input variable section mass of firewood, specific heat capacity of firewood, thermal conductivity of clay, temperature of oven, thickness of the oven wall, thickness of the floor, ambient temperature and lastly radius of oven. The third section only has surface area of clay oven pre-determined or radius and height of the clay oven chamber. The fourth section also has pre-determined floor area or length and breadth of the floor input. The fifth section command button evaluates the data and generates result of energy, energy losses and exergy into section 6. Exergy calculation was carried out by clicking on the exergy option at the top of the interface in Figure 3 and all the input variable are captured in the text boxes provided. Calculation was done by clicking on the "calculate" button at lower left end of the interface. This quantifies the exergy from firewood in the clay oven and can be in the reverse order to calculate the mass of wood for a known quantity of exergy.

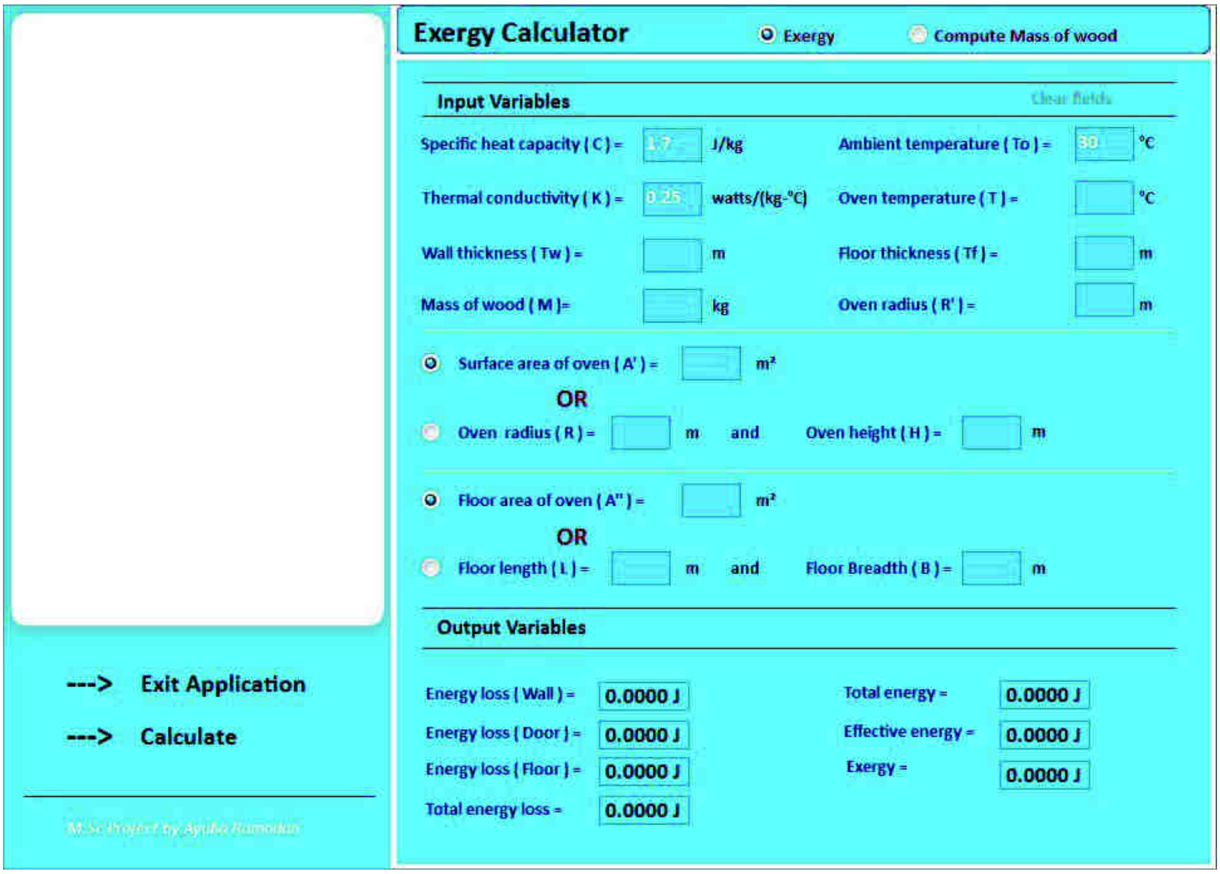

Figure 3. Graphical user interface for exergy calculator

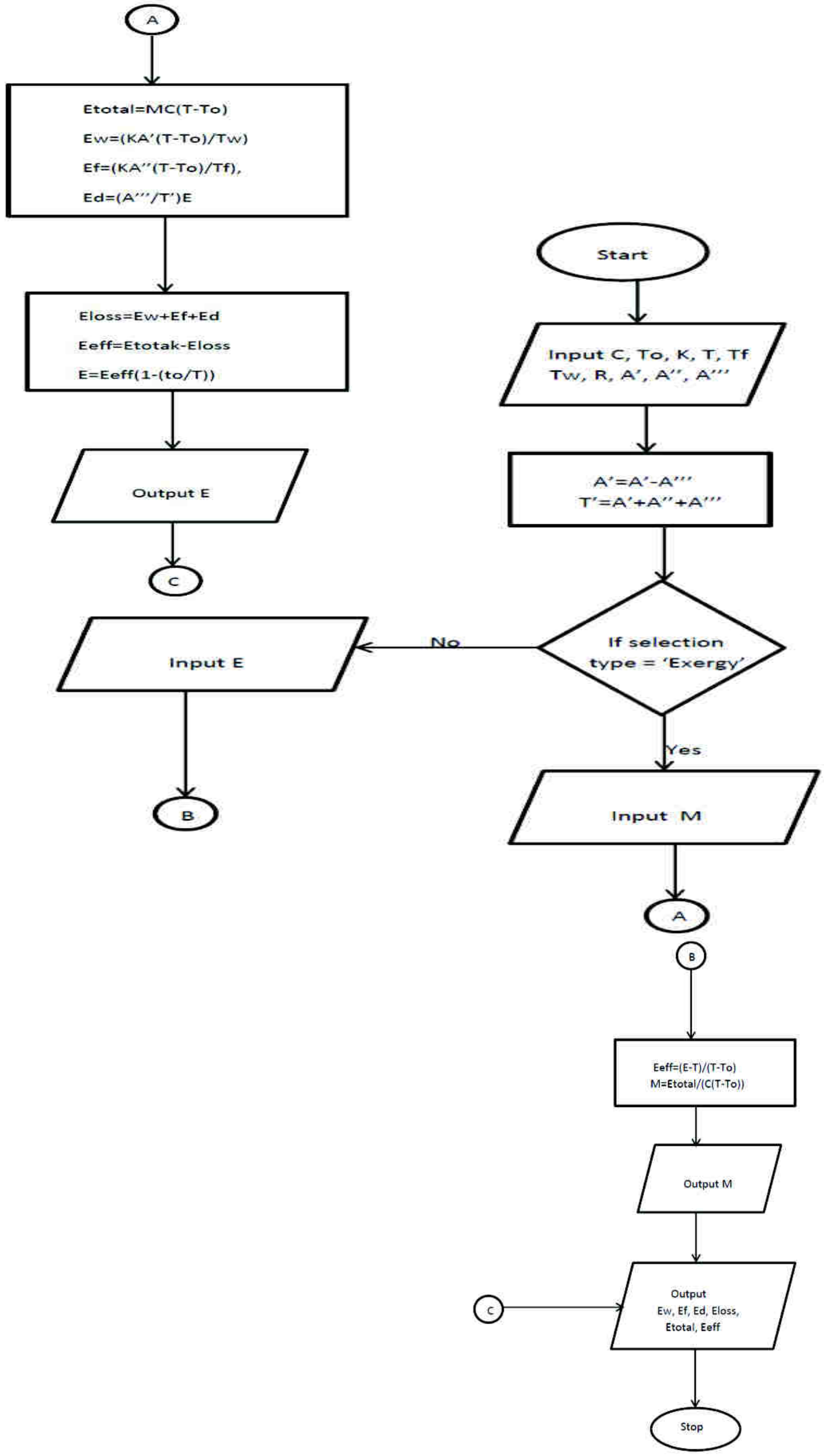

Figure 4. Flow chart of exergy estimation process

4. CONCLUSION

Based on the research carried out, it was concluded clay oven has high heat retention properties. Using the investigated clay ovens to bake dough produced from 300 kg wheat flour, peak energy, exergy and temperature respectively were 184.8MJ, 169.3MJ and 451^{o}C and were attained at 180 minutes heating duration using 258.4 kg of firewood as energy source. Energetic and exergetic efficiency of clay oven were 74.7% and 72% respectively. The developed computer software is a useful tool for estimating energy distribution pattern in clay oven. It saves time with high level of accuracy.

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