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The Effect of Cow-dung Stabilisation on Combustion and Thermal Comfort of Soil Housing Materials

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ABSTRACT: *Fire and thermal properties are very important requirements in material selection whether local or imported especially in hot and dry climates. This study investigated the stabilising effect of cow-dung powder, well-known biofuel on the combustion and thermal comfort of soil-integrated buildings. Soil bricks and cube measuring 215x105x80 mm and 50x50x50 mm were prepared with 0%, 5%, 10%, 15% and 20% cow-dung powder by weight of the soil. A total of 40 samples were produced comprising of 20 bricks and 20 cubes. The samples were labelled as A_0 for the control and B_5, B_{10}, B_{15} and B_{20} for samples with cow-dung content. The samples were air-dried in a laboratory environment for 28 days before they were tested for combustion and heat capacity. Combustion increased from 0.58% for the control to 1.03% for the 20% cow-dung content samples representing 77.6% appreciation. Again, heat capacity of the stabilised samples also increased from 3.35 Cal/C° for the control samples to 5.01 Cal/C° for the 20% cow-dung content samples representing 49.6% increment. Beyond the 15% to the 20% cow-dung additions, it was observed that the percentage increase of both combustion and heat capacity was minimal. Though materials with high heat capacities tend to exhibit more thermal comfort, 15% cow-dung can be considered as the optimum percentage for the purpose of strength requirements.*

KEYWORDS: *Cow-dung powder, soil bricks/cubes, combustion, heat capacity, thermal comfort*

I. INTRODUCTION

Historically, soil architecture has been used for centuries as the cheapest means of providing housing needs to a large number of people. Archaeological evidence in very dry climates had proven that many houses and other structures were built from soil material or soil that was compressed and dried into bricks. Soil-built houses, according to modern housing literature are still alive and patronised in many parts of the world where access to other forms of materials is restricted by cost or location [1]. The most tangible proof of this assertion is the continued use and existence of many thousands of new and historic traditional soil-built houses such as rammed, cob, wattle and daub, dotted across the length and breadth of both developed and developing countries. Previous studies have shown that soil-built houses offer a number of benefits to human life. Firstly, it is ecofriendly due to its low embodied energy content and low environmental impact. This is because soil is locally obtained with minimal transportation costs and used in its natural state; hence no fossil fuel is needed for processing. Secondly, soil-built houses can boost of excellent sustainability credentials combined with good thermal and acoustic properties [2]. For instance, the energy required to process soil material for building is only 5 kwh per cubic metre, as compared to 1000 kwh per cubic metre for fired clay bricks and 400-500 kwh per cubic metre for concrete as presented in Table 1 [3].

Table 1: Energy Requirements

Material	**Unit**	**Energy (kwh)**
Soil brick	m^3	5
Fired clay brick	m^3	1000
Concrete	m^3	400-500
Cement	m^3	50

On the contrary, it has been found that soil-built houses deteriorate very fast due to adverse weather conditions of high rainfall and thermal cycling [4]. To overcome this challenge, soil material is stabilised to improve it characteristics so that it can tolerate greater loading and perform better when it is exposed to the weather elements [5-6]. The two most common techniques used in soil stabilisation are binding (with chemical additives such as cement and lime) and increasing the density (through compaction). Earlier studies have found that cement and lime are suitable stabilisers for use with soil in the production of soil bricks and blocks [7]. As stabilising materials, cement and lime are well researched, well understood and their properties clearly defined. Cement and lime are readily available in all countries all over the world, as it is one of the major components for any building construction [7]. However, due to increase cost relating to cement and lime production and environmental concerns, soil stabilisation with cement and lime is less appreciated [8-9]. Furthermore, it has also been established that lime particularly is not suitable for soils which contain sulphates as the presence of sulphates can increase the swelling due to the formation of swelling minerals such as ettringite and thaumasite [10].

Presently, research efforts are being directed towards housing cost affordability and environmental protection by using alternative locally-sourced soil stabilisation additives to minimise the negative impact on the environment caused by the production process of cement and lime [2]. Furthermore, healthy and comfortable indoor environment have become important in the selection and use of local-based additives for the stabilisation of soil-built houses [11]. Traditionally, the architecture of African cultures evolved out of the search for suitable solutions to climatic challenges against living conditions [12]. It is against this background that new trends and standards for sustainable soil-housing architecture using locally-sourced soil materials and additives are being imposed. It has been found that houses made from soil material and local-sourced agriculture-based soil stabilisation additives such as clay, adobe, ashes, straws, fibres, shells, animal excreta and so on in which people once lived are becoming increasingly attractive because the inner environment of such houses are warmer in winter and cool in summer.

One agricultural-based waste found to exhibit soil stabilisation properties due to the presence of insoluble silica amine, undigested plant fibre and oil is the cow-dung. Cow-dung is the excreta of the bovine animal species such as cattle. It has been found that the excreta of cows (cow-dung) contain some amounts of undigested plant residue because of the herbivorous nature of the cows [13]. The stabilisation of soil material with cow-dung increases the coefficient of friction and wearing resistance of the compressed material [14]. Existing studies on the use of cow-dung as partial replacement of cement for concrete and mortar production [15,16,17] and soil stabilisation for soil bricks and blocks production [18,19] focused on the compressive strength, split tensile strength, flexural strength, water absorption, and scanning electron microscope (SEM) tests.

From literature, it is established that dried cow-dung is highly combustible and for this reason makes it an excellent fuel for the firing of clay pots and other earthenware in pottery kilns in rural communities in Africa [18]. However, the combustible effect of cow-dung on stabilised compressed soil structures has not yet been investigated. Thus, this present study investigated the effect of cow-dung on the combustion resistance and heat capacity of stabilised soil material for soil-integrated buildings.

II. MATERIALS AND METHODS

Materials

The following materials were carefully selected and used to prepare the the brick test samples for the study: dried cow-dung cakes, lateritic soil and water

Dried cow-dung cakes

Cow-dung is the excreta or waste product of the bovine animal species such as cattle. It is the undigested residue of plant matter which has passed through the animal's gut. Fresh cow-dung was obtained from a large cowshed (kraal) located in Fielmuo, a fast growing farming community along the Ghana-Burkina Fasso border in the Sissala west district of the upper west region of Ghana

Cow-dung is abundant in and around the community due to the large numbers of cows owned and reared by almost every family.

Lateritic soil

Well and uniformly graded lateritic soil material was used for the study. An undisturbed soil sample was taken from a pit at a depth of 500 mm below the uppermost layer purposely to exclude organic soils from being part of the test samples. This type of soil was used because ot it coarseness, as less than 31% of it particles is finer than 0.06 mm. The soil has liquid limit between 25% and 35% and plasticity index between 2.5% and 15% which makes it suitable to be stabilised with tar-like and herbivorous substances produced by plants and animals.

Water

Fresh, drinkable, colourless, odourless and tasteless tab water supplied by the Ghana Water Company Limited to the laboratory was used to prepared the test samples. The choice of water from this source was necessary to avoid chemicals and other reactive impurities that maybe found in unclean water that may have the potential to interfere with the stabilising properties of the cow-dung.

Methods and procedures

Cow-dung cakes milling preparation

Freshly shit cow-dung was scooped in the cowshed with a hand trowel into a clean transparent plastic container with a lid. The green cow-dung sample was taken to the Building Technology and Civil Engineering laboratory of the Dr. Hilla Limann Technical University, Wa, Ghana, to be air-dried in a room temperature for a period of 14 days to constant weight. The weight was considered constant when the difference between the weightings in day thirteen and day fourteen was zero percent. The dried cake-like pieces of the cow-dung (Fig. 1) were first crushed to smaller pieces using a Thomas grinding machine. The pieces or particles were futher milled to fine particle size using a cone crusher and sieved through a 0.4 mm sieve. The fine cow-dung particles or powder that passed through the sieve (Fig. 2) was used to stabilised the lateritic soil bricks for the experimental study.

Fig. 1 Dried cow-dung cakes

Fig. 2 Milled cow-dung powder

Soil classification

The soil sample was first passed through a 5 mm network of sieves to ensure that stones and other foreign matter were removed, before it was characterised to assess the index properties in line with BS1377-2 [20]. The purpose of the soil test was to ascertain the suitability of the soil material used for preparing the samples for the tests. To determine the predominant size particles that form the soil and which is necessary to control the bulk density of the compressed soil body, the sieve analysis test was conducted. The assessment of the soil type from the silt, clay and sand/gravel fractions through sedimentation test was performed using the jar method. The Atterberg's limit test was also conducted to determine the strength and class of the soil. Other tests performed were linear shrinkage, specific gravity, organic content and natural moisture contents.

Mix design

The soil material was prepared with a constant soil-water mixture of 12% water and compaction pressure of 8 MN/m^2 for the brick samples for the combustion test. For the heat capacity test, the soil were moulded into cubes. The amount of water used was per the optimum moisture content (12%) by weight of the soil and the recommended optimum compaction pressure for soil block/brick production. In order to find out the effect of variation in cow-dung on combustion resistance and heat capacity (thermal comfort), the soil mixtures had their cow-dung contents varied from 0%, 5%, 10%, 15% and 20% by weight of the soil. The soil and cow-dung powder were first mixed in a dry state manually to form a uniform mixture. Water was added in two phases and mixed to a semi-dry uniform colour and consistency. The soil was then moulded into bricks (Fig. 3) and cubes (Fig. 4) using the BREPAK brick press and metallic mould boxes respectively, and labelled as A_0 for the control; B_5, B_{10}, B_{15} and B_{20} for bricks with 5%, 10%, 15% and 20% cow-dung contents (expermental bricks). The bricks and cubes were stored and cured in a laboratory environment for 28 days. A total of twenty number each bricks of size 215x105x80 mm and cubes of size 50x50x50 mm were produced for the combustion and heat capacity tests respectively.

Fig. 3 Bricks being cured

Fig. 4 Cubes being cured

Test procedures

The cow-dung used as the stabiliser has some elements of combustible properties due to it oily content that makes it an excellent bio-fuel. It was therefore necessary to test the stabilised soil bricks to determine the degree of combustion or flame spread when subjected or exposed to excessive heat. The test brick samples were first cleaned of any loose matter after which they were weighed and the mass recorded (M_1). The bricks were then burnt in an electric oven shown in Fig. 5 at a high temperature of 140 degrees celsius. The burning was continued for sixty (60) minutes when there was no visible sign of fume or gas. The burnt bricks were removed from the oven and allowed to cool and the burnt weight measured (M_2). The difference between the brick sample masses before and after burning was measured and the loss in weight expressed as a percentage of the weight before burning using equation 1.

Percentage loss of weight = (M_1-M_2/M_1 x 100 eq. 1

Where M_1 is the mass of brick before burning and M_2 is the mass of brick after burning.

Fig. 5 Burning of bricks in an electric oven

The heat capacity of a material is the quantity of heat needed to raise its temperature 1 degree celsius, and is used to measure the thermal comfort of structures built with the material. To determine the heat capacity of the cow-dung stabilised cubes, the soil cubes were first dried to constant weights in the laboratory. The weights were considered constant when the difference between two weightings was zero. This was to ensure that the cubes have the same weight and for that matter density. Three number cubes that have no visible signs of cracks were selected from each stabilisation level for the test. The cubes were further cleaned thoroughly to remove any loose material or particles on them. the cubes were then put in an electric oven (Fig. 6) and heated at a temperature of 140 degrees celsius for 15 minutes. The cubes were removed and immediately the rise in temperature was measured using the laboratory glass thermometer. The measurements were recorded and the heat capacities in calorie per degrees celsius (cal/C^o) computed using equation 2.

Heat capacity = Q/ΔT eq. 2

Where Q is the quantity of heat needed to produce a change in the temperature of the cube and ΔT is the rise in temperature.

Fig. 6 Cubes being heated in an oven

III. RESULTS AND DISCUSSION

Soil properties

The geotechnical properties of the soil studied are listed in Table 2. The soil had a coefficient of uniformity (C_u) of 7.3 and coefficient of gradation (C_g) of 2.1. Any soil having coefficient of uniformity greater than 6 (C_u> 6) and coefficient of gradation greater than 1 and less than 3 (1 < C_g< 3) is a well graded clay soil of intermediate plasticity [21]. The soil recorded a silt content of 14%, clay content of 17% and a high sand/gravel content of 69%. This moderate clay content satisfied the requirement that suggests that an optimum fine content should be about 25%, of which more than 10% should be clay. The fines content per this results is 31%, of which the clay fraction is 17%. Again, the soil had a liquid limit of 34%, plastic limit of 20% and plasticity index of 14%. These values fall within the preferred range of between 30%-35% for liquid limit and 12%-22% for plastic limit recommended in literature [22,23], and according to the plasticity chart for soil classification, the soil used could be classified as moderately plastic clay. Furthermore, the soil obtained a percentage shrinkage value of 4.9%, less than the recommended 6%, and a specific gravity value of 2.69, which is between the lower and upper limits (2 and 2.8) recommended for soil material for housing in Ghana [1][24]. Thus, the values of all the soil properties studied satisfied the suitability limits and ranges reported in literature.

Table 2 Summary of soil properties

Constituent	Value
Soil colour	Brownish red
Sieve analysis	C_u=7.3 and C_g=2.1
Silt fraction	14%
Clay fraction	17%
Sand/grave/ fraction	69%
Liquid limit	34%
Plastic limit	20%
Plasticity index	14%
Shrinkage limit	4.9%
Specific gravity	2.69
Organic matter content	1.8%
Natural moisture content	6.7%
Optimum moisture content	12%

Cow-dung chemical properties

Some chemical properties of cow-dungalready studied and documented in literature [17] are also presented in Table 3. It has a very high potassium content of 53.06% by weight and 70.12% atomic. The total silica + aluminium oxide + iron oxide present in cow-dung was lower than the minimum 70% specified for supplementary cementitious materials that produce pozzolanas.

Table 3 Chemical properties of cow-dung

Element	Weight (%)	Atomic (%)
Potassium	53.06	70.12
Magnesia	1.02	0.89
Aluminium oxide	4.68	3.66
Silica	18.16	13.90
Calcium oxide	16.68	9.80
Magnesium	1.15	0.06
Iron oxide	3.23	1.84
Copper	2.02	0.44

Combustion resistance

The stabilised soil brick combustion resistance test results are presented in Table 4 and plotted in Fig.7. Brick samples without cow-dung content recorded an average percentage combustion of 0.58%. Combustion then increased steadily to 0.71%, 0.83%, 0.97% and 1.03% for the 5%, 10%, 15% and 20% cow-dung stabilised bricks respectively. It is evident that the more the inclusion of the cow-dung, the higher the combustibiliy or flame spread. However, beyond the 15% cow-dung stabilisation content, there was a minimal increase of combustion percentage value for the 20% stabilised cow-dung content brick samples. This increasing behavioral trend shows that there might be an optimum cow-dung addition percentage stabilisation for combustion resistance or flame spread, since the bar above the 20% cow-dung content almost levelled off with the bar above the 15% cow-dung stabilisation level (Fig. 7).

Table 4 Combustion test results (%)

Cowdung (%)	Sample			Ave. (%)	SD
	1	2	3		
A_0	0.56	0.54	0.64	0.58	0.05
B_5	0.67	0.80	0.67	0.71	0.08
B_{10}	0.76	0.95	0.79	0.83	0.10
B_{15}	0.89	1.02	1.00	0.97	0.07
B_{20}	1.12	1.12	0.86	1.03	0.15

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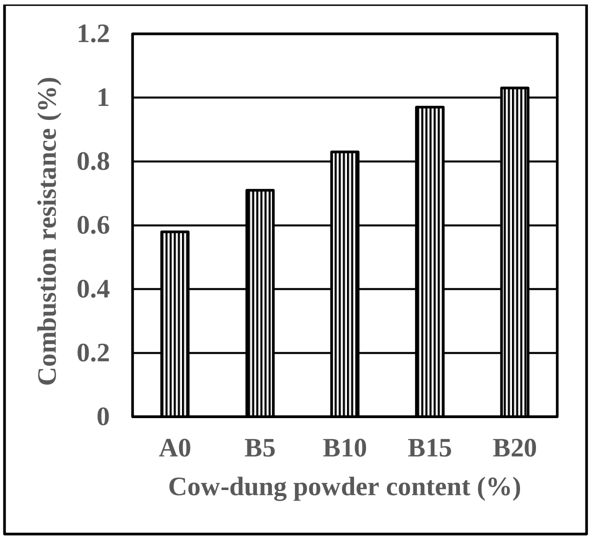

Fig. 7 Variation of combustion with cow-dung content

Both local practice and research findings have shown that dried cow-dung cakes or pieces can be used as bio-fuel [18]. Hence, the steady increase in combustion observed in Table 4 and Fig. 7 was expected because cow-dung is reported to have some traces of undigested plant fibre mixed with oily substances that could easily be inflamed. This implies that it would be unsafe to use soil material stabilized with cow-dung in the erection, plastering or screeding of soil-built houses exposed to excessive heat unless protected in some form.

One-way ANOVA test to a significant level of 0.05 was performed to compare the mean combustion percentage values. From Table 5, the F-value obtained showed a high variability between the different stabilisation levels of the bricks than variability within each level: $F(4,10) = 11.095$; $p < 0.05$. This therefore indicates that the addition of the cow-dung has an influence on the combustion behaviour of the stabilised soil bricks.

Table 5 ANOVA analysis of combustion of bricks (%)

Source of variation	Sum of squares	df	Mean squares	F	P
Between groups	0.411	4	0.103	11.095	0.001
Within groups	0.093	10	0.009		
Total	0.504	14			

Heat capacity

Thermal absorption and transmission rate of the cow-dung stabilised soil cube samples was measured by evaluating the heat capacities of the test samples. From the test results presented in Table 6 and Fig. 8, the control soil cubes produced the lowest heat capacity of 3.35 Cal/Cº. This increased steadily to 3.74 Cal/Cº, 4.24 Cal/Cº, 4.67 Cal/Cº and 5.01 Cal/Cº for the 5%, 10%, 15% and 20% cow-dung powder stabilisation levels respectively. It is noticed that the percentage increased of the heat capacity from the 10% to the 15% cow-dung addition was 10.14%, but from the 15% to the 20% cow-dung contents, the percentage increase reduced to 7.7%. Once again, the percentage reduction of the heat capacity from the 15% to the 20% cow-dung addition shows that there might be an optimum with further addition. It was further observed that heat capacity increased with decreased in the cubes density.

Table 6 Heat capacity test results (Cal/Cº)

CD (%)	Sample (Cal/Cº) 1	2	3	Ave.	SD	Density (kg/m^3)
A_0	3.33	3.04	3.68	3.35	0.320	1264
B_5	3.59	3.50	4.24	3.74	0.430	1088
B_{10}	4.38	4.67	3.68	4.24	0.509	1032
B_{15}	4.00	4.83	5.19	4.67	0.610	965
B_{20}	5.83	4.38	4.83	5.01	0.774	963

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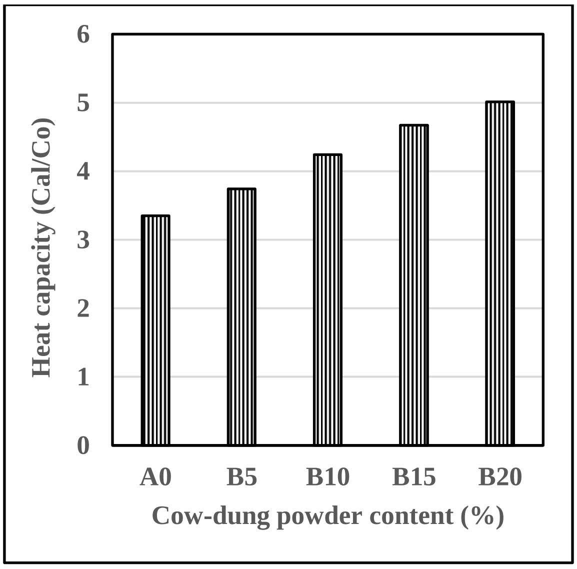

Fig. 8 Variation of heat capacity with cow-dung content

The heat capacity results showed similar variation to that of the combustion resistance results and once again could be linked to the high content of undigested plant fibre and oily substance content in the cow-dung used to stabilized the soil cubes. It has been established in literature that materials with high heat capacities warm more slowly because they must absorb greater quantity of heat; they also cool more slowly because they must give out more heat [25]. From this assertion, it is evident that the addition of the cow-dung in the soil material increased the heat capacity of the soil cubes. This observation explains why rooms of traditional soil-built houses with cow-dung contents remain cool in sunny days and warm in the cold night compared to rooms in houses built without cow-dung contents. The presence of the cow-dung makes it possible for the soil-built walls to absorb heat from the external environment more slowly during the day time allowing the rooms to remain cool and give out heat more slowly to the external environment allowing the rooms to remain warm during the night.

Table 7 ANOVA analysis of heat capacity of bricks (%)

Source of variation	Sum of squares	df	Mean squares	F	P
Between groups	5.455	4	1.364	4.639	0.022
Within groups	2.940	10	0.294		
Total	8.395	14			

An analysis of variance (ANOVA) test was conducted purposely to determine the contribution of the cow-dung to the heat capacity development behaviour. From the predictive (p) value shown in Table 7, it is observed that cow-dung contributed substantially to the heat capacity behaviour; $F(4,10) = 4.639$, $p < 0.05$.

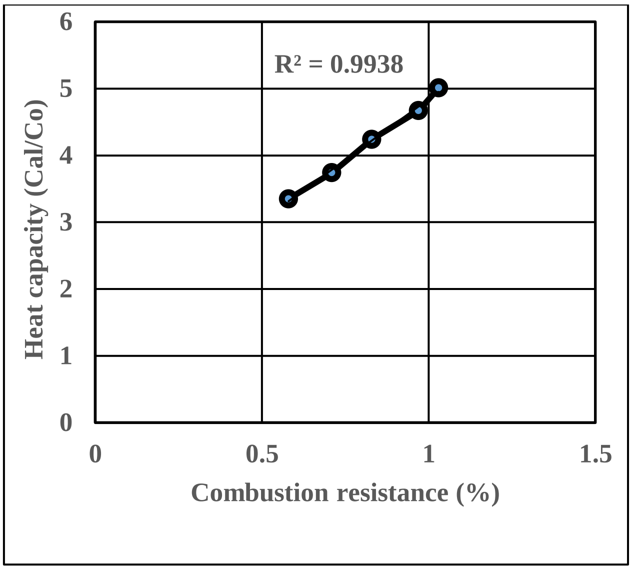

Fig. 9 Relationship between combustion and heat capacity

Again, a Pearson Product-Moment Correlation test was conducted to determine the relationship between combustion and heat capacity of the cow-dung stabilised soil cubes. From Fig. 9, the results indicate a strong positive linear relationship between combustion and heat capacity with coefficient of determination (R^2) of 0.994. This means that the cow-dung content in the soil cubes increased combustion with corresponding increased in the heat capacity behaviour. In other words 99.4% of the increase in the combustion of the soil bricks could be explained by the increased in the heat capacity of the soil cubes.

From the results for both combustion and heat capacity, an optimum cow-dung percentage addition has not been obtained. However, the difference between combustion percentage values and heat capacity at the 15% and 20% cow-dung addition contents showed a minimal increasing trend. In previous studies, the optimum cow-dung percentage addition for soil brick stabilisation and cement replacement for concrete production that yielded maximum compressive strength properties was established at 15% cow-dung addition for stabilised soil and cement replacementfor soil brick and concrete productions [15,16].

IV. CONCLUSION

In this paper, combustion resistance and heat capacity of soil bricks and cubes stabilised with cow-dung powder were studied to determine flame spread and thermal comfort levels respectively in traditional soil-integrated buildings. The findings indicate that the inclusion of cow-dung in the soil bricks and cubes has an influence on combustion and heat capacity behaviour of the test samples. For instance, with the addition of up to 20% cow-dung powder, combustion (flame spread) of the stabilised soil bricks increased from 0.58% for the control bricks to 0.71%, 0.83%, 0.97% and 1.03% for the 5%, 10%, 15% and 20% cow-dung content bricks respectively. In a similar trend, heat capacity also increased from 3.35 Cal/Cº, for the control cubes to 3.74 Cal/Cº, 4.24 Cal/Cº, 4.67 Cal/Cº and 5.01 Cal/Cº for the 5%, 10%, 15% and 20% cow-dung content levels respectively. This steady increasing trend of both combustion and heat capacity is evident in the correlation analysis performed. Both parameters studied (combustion and heat capacity) are positively correlated with R-square of 0.994. This implies that an increase in combustion caused a significant increased in the heat capacity.

An optimum percentage addition of the cow-dung for combustion and heat capacity (thermal comfort) of the soil bricks and cubes was not clearly obtained. However, it could be seen that 15% and 20% percentage additions are suitable to minimise combustion and increase heat capacity that could lead to thermal comfort in soil-built housing rooms since the bars of the charts almost levelled off above the 15% cow-dung percentage addition. For the purpose of strength considerations and as established in previuos studies, the present study recommends that 15% cow-dung by weight of the soil can be added to the soil as the optimum dosage to get favourable combustion resistance and heat capacity that could lead to healthy and comfortable indoor thermal environment in soil-built houses. Therefore, for the purpose of combustion and thermal comfort, as well asstrength considerations, the results of this study provide a strong support for the use of cow-dung powder for soil stabilisation for soil-integrated housing provision.

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REFERENCES

[1]. H. Nawar, Soil properties for earth building construction in city of Zakho-Iraq, *PalArch's Journal of Archaelogy of Egypt/Egyptology, 17(7),* ISSN: 1567-214X, 2020, pp. 10441-10458

[2]. J. Jijo, & P. K. Pandian, Performance study on soil stabilisation using natural materials. *International Journal of Earth Sciences and Engineering, ISSN: 0974-5904, Volume 06, Number 01*, 2013, pp. 194-203

[3]. Y. K. A. Al-Sakkaf, *Durability properties of stbilised blocks*, Doctorate Dissertation, Univrsity Sains Malaysia, 2009, pp. 1-246

[4]. E. Osei-Tutu, & A. Ofori, Towards the enhancement of earth buildings in Ghana, *The Ghana Surveyor, Volume 2, Number 1*, 2009, pp. 50-61

[5]. O. A. Olowu, A. A. Raheem, E. M. Awe, & G. O. Bamigboye, Enhancing the mechanical properties of lateritic brick for better performance, *International Journal of Engineering Research and Applications, ISSN: 2248-9622, Volume 4,* Issue 11, 2014, pp. 01-07

[6]. J. Vyncke, L. Kupers, & N. Denies, Earth as building material – An overview of RILEM activities and recent innovations in geotechnics, *MATEC Web of Conferences,* 2018, 149, 02001

[7]. M. N. Hassoun, & A. Al-Manaseer, *Structural concrete: Theory and Design* (6^{th} edition). John Wiley & Sons Inc. Hoboken, New Jersey, 2015

[8]. A. K.Sharma, & P. V. Sivapullaiah, Soil stabilisation with waste materials based binder. *Proceedings of Indian Geotechnical Conference,* December 15-17, 2011, Koche (Paper No. H-119), pp. 413-416

[9]. H. Danso, & S. Adu, Characterisation of compressed earth blocks stabilised with clay pozzolana. *Journal of Civil & Environmental Engineering, Volume 1,* Issue 1, 1000331. DOI: 10.4172/2165-784X.1000331, 2019, pp. 3-6

[10]. G. Rajasekaran, Sulphate attack and ettringite formation in the lime and cement stabilised

marine clays. *Journal of Ocean Engineering, 32*, 2005, pp. 1133-1159

[11]. N. Jamaludin, N. I. Mohammed, M. F. Khamidi, & S. N. A. Wahab, Thermal comfort of residential buildings in Malaysia at different micro-climates. *Procedia-Social and Behavioural Sciences, 170*, 2015, pp. 613-623

[12]. O. E. Anselm, & A. F. Ojonigu, The influence of rainfall on Hausa traditional architecture. *Research Journal of Applied Sciences, Engineering and Technology, Volume 2, Issue 8,* 2010, pp. 695-702

[13]. P. Magudeaswaran, & A. S. Hilal, Development of eco-efficient brick and concrete with the partial replacement of cow dung. *International Journal of Science and Engineering Research (IJOSER), Volume 6*, Issue 5, 2018

[14]. Y. Ma, S. Wu, J. Zhuang, J. Tong, & H. Qi, Tribological and physio-mechanical characterisation of cow dung fibres reinforced friction composites: An effective utilisation of cow dung waste. *Tribology International, 131*, 2019, pp. 200-211.

[15]. D. Ramachandran, V. Vinita, & K. Viswanathan, Detailed studies of cow dung ash modified concrete exposed in fresh water, Journal of Building Engineering, Volume 20, pp. 173-178

[16]. D. Kamat, O. Gupta, A. Palyekar, V. Naik, V. Khadlikar, A. Kudchadkar, & K. V. P. Fondekar, Use of cow dung ash as a partial replacement for cement in mortar. *International Journal of Engineering Research and Technology (IJERT), ISSN: 2278-0181, Volume 9,* Issue 14, 2021, pp. 7-9

[17]. K. Farhan, M. Pratiksha, B. Rajshri, T. Rupal, & N. Sakshi, Experimental analysis on the use of plant fibre as a sustainable replacement for fine aggregate and cement in concrete. *Advances and Applications in Mathematical Sciences, Volume 21*, Issue 9, 2022, pp. 5209-5221

[18]. P. Y. Millogo, E. J. Aubert, A. D. Sere, A. Fabbri, & C. J. Morel, Earth blocks stabilised by cow dung. *Materials and Structures, 49(*11), 2016, pp. 4583-4594

[19]. S. J. Adekanmi, O. O. Popoola, & S. M. Afolabi, Short-term investigation to the effectiveness of cow dung powder on lime stabilised tropical soil in road construction. *IOSR Journal of Mechanical and Civil Engineering, e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 19,* Issue 2, Ser 111, pp. 51-57

[20]. BS 1377-2, Methods of test for soils for civil engineering purposes, Part 2: Classification tests and determination of geotechnical properties, 2022.

[21]. A. Aysen. *Soil mechanics: Basic concepts and engineering applications.* Taylor and Francis Groups plc, London, UK, 2005, pp. 1-457.

[22]. H. Houben, & H. Guillaud, Earth construction: A comprehensive guide. London, Intermediate Technology Publications, 2006.

[23]. P. R. Chaudhari, & V. D. Ahire, Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *International Journal of Scientific and Research Publications, 3(2*), 2013, pp. 1-8.

[24]. H. Danso, Suitability of soil for earth construction as building material. *Advancements in Civil Engineering & Technology, Volume 2, Issue 3,* 2018, pp. 199-211.

[25]. J. E. Williams, F. E. Trinklein, & H. C. Metcalfe, *Modern Physics*. Holt, Rinehart and Winston Publishers, United State of America, ISBN: 0-03-089763-7, 1976, PP. 1-724