DEVELOPMENT OF THERMAL EFFICIENT NON FIRED BRICKS USING IRON ORE TAILINGS AND PERLITE

Thesis

Submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

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DECLARATION

by the Ph.D. Research Scholar

I hereby *declare* that the Research Thesis entitled "**Development of Thermal Efficient Non Fired Bricks using Iron Ore Tailings and Perlite**" which is being submitted to the National Institute of Technology Karnataka, Surathkal in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in **Mining Engineering** is a *bonafide report of the research work carried out by me*. The material contained in this Research Thesis has not been submitted to any other Universities or Institutes for the award of any degree.

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CERTIFICATE

This is to certify that the Research Thesis entitled "**Development of Thermal Efficient Non Fired Bricks using Iron Ore Tailings and Perlite**" submitted by **Mr. P. Shubhananda Rao (Register Number:** 165018MN16P01) as the record of the research work carried out by him, *is accepted as the Research Thesis submission* in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy.

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ABSTRACT

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Brick is the most basic artifact and plays a very important role in the construction of buildings. The construction industry is in need of easily available, economically feasible and green materials, as there is a scarcity of naturally available river sand. A lot of research is going on to improve mechanical properties of bricks and also to make more environmentally friendly and economical. A systematic study is taken up by manufacturing bricks using iron ore tailings and additives like perlite. The physical and chemical properties of the materials used in the bricks were determined as per Indian Standard (IS) codes.

Use of iron ore tailings (IOT) found to be very beneficial in this research, and the addition of perlite as an admixture to improve its thermal properties is given scope for the development of non-fired thermal efficient bricks. These are non-burnt bricks manufactured in a non-traditional method, which creates a cleaner and greener environment.

Bricks were made using different proportions, by replacing sand with Iron Ore Tailings from 30 to 60 percent at 10 percent interval, cement from 10 to 20 percent at 5 percent interval, and Perlite at 2 and 5 percent, of 230mmX112.5mmX75mm dimensions. The study on eco-friendly bricks aims to assess the suitability of IOT in construction in terms of strength, durability, percentage of water absorption and thermal conductivity. Based on laboratory experiments, the optimum percentage of mix to make bricks consisting of iron ore tailings, sand, cement, and perlite was found to be 50%, 25%, 20%, and 5% respectively. The optimum mix gave a compressive strength 3.89MPa, water absorption 14.82% and thermal conductivity 0.920 W/mk which are well within IS codes.

Based on the positive laboratory results, further a pilot-scale study is taken up with IOT-perlite bricks. In order to assess the effectiveness of IOT-perlite bricks, the pilot-scale study also planned with locally available conventional bricks (fired bricks). Two model rooms, one with IOT – perlite bricks and the other with conventional bricks are constructed to assess the effectiveness of thermal conductivity. It is assessed by measuring the temperature on all sides of the walls at different timings of the day. The results revealed that heat transferred from the outside surface to the inside surface of the bricks in the walls of the model room constructed with IOT-Perlite bricks was less compared with the room constructed with ordinary bricks. Lower thermal conductivity of IOT-Perlite bricks will tend to have less room temperature compared to the ordinary brick room. The reduction in the temperature of the IOT-Perlite brick room will consume less electricity and it was estimated in terms of energy savings will be around 8 percentage. The study proved that eco-friendly bricks by using IOT will have lower thermal conductivity, better strength and lightweight in structure.

Regression models are developed to predict strength and durability properties like density, compressive strength and thermal conductivity. The regression fit between actual and predicted values in all cases showed a very good correlation.

Keywords: Bricks, iron ore tailings (IOT), perlite, compressive strength, water absorption, thermal conductivity, energy-saving, statistical analysis

ACRONYMS

IOT -	Iron Ore Tailings
ROM-	Run Off Mine
UCS-	Unconfined Compressive Strength
GHG-	Green House Gases
CSEB-	Compressed Stabilised Earth Blocks
MSW-	Mine Spoil Waste
ECC-	Engineered Cementitious Composite
SMB-	Stabilised Mud Blocks
NMI-	National Mineral Inventory
UNFC-	United Nation Framework Classification for Resources
GGBS-	Ground Granulated Blast Furnace Slag
EPA-	Expanded Perlite Aggregate
CMC-	Carboxy Methyl Cellulose
ELO-	Epoxidized Linseed Oil
FA-	Fly Ash
EP-	Expanded Perlite
EPC-	Expanded Perlite Concrete
KEL-	Keltech Energies Limited
Cu-	Uniformity coefficient
Cc-	Coefficient of curvature
D_{50}-	Median diameter
Wa-	Water Absorption
k-	Thermal conductivity
ASTM-	American Society for Testing & Materials
IS-	Indian Standards
BIS-	Bureau of Indian Standards
LCD-	Liquid Crystal Display
ANOVA-	Analysis of Variance
AAC-	Autoclaved Aerated Concrete
PP-	Polypropylene
GHG-	Green-House Gas
OPC-	Ordinary portland cement

ANSYS-	Analysis System
XRD-	X–Ray Diffraction
XRF-	X–Ray Fluorescence spectroscopy
SEM-	Scanning Electron Microscopy
EDX-	Energy Dispersive X-ray
TGA-	Thermo-gravimetric analysis
SBR-	Styrene- Butadiene Rubber
UCS-	Uniaxial Compressive Strength
IRC-	Indian Road Congress
IOW-	Iron Ore Waste
MG/kg-	Mega Joule per Kilogram
mm-	Milli-meter
gm-	Gram
g/cc-	Gram per cubic meter
kg/m^3-	Kilogram per cubic meter
Mt-	Million tonnes
PPM-	Parts per million
W/mk-	Watts per meter-kelvin
MPa-	Mega Pascal
N/mm^2-	Newton per square milli-meter
CO_2-	Carbon Dioxide
CO-	Carbon Monoxide
NO_2-	Nitrogen Dioxide
CH_4-	Methane
SiO_2-	Silicon oxide
Al_2O_3-	Aluminium oxide
Fe_2O_3-	Iron oxide
CaO-	Calcium oxide
Na_2O-	Sodium oxide
MgO-	Magnesium oxide
MnO-	Manganese oxide
K_2O-	Potassium oxide
ZnO-	Zinc oxide
CuO-	Copper oxide

PbO-	Lead oxide
LOI-	Loss of Ignition
H_3PO_4-	Phosphoric acid
Na_2SiO_3-	Sodium silicate
Ni-	Nickel
Cu-	Copper
Si-	Silicon
Al-	Aluminium
K-	Potassium
O-	Oxygen
Na-	Sodium
Fe-	Iron
Ca-	Calcium
Mg-	Magnesium

MATHEMATICAL SYMBOLS

(+)	Addition
(-)	Subtraction
(/)	Division
(x)	Multiplication
>	Greater Than
<	Lesser Than
=	Equal to
( )	Round Bracket
[ ]	Square Bracket
Π	Pi
√	Square Root
%	Percentage
||	Modulus
^{o}C	Degree Celsius
^{o}F	Degree Fahrenheit
α	Alpha
µ	Micro

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CHAPTER - 1

INTRODUCTION

This chapter gives brief introduction to the problem being considered in this research and the importance of finding sustainable solution to address it. It includes the aim and the specific objectives of the research work. This is followed by the scope and explanation of how this thesis has been structured for easy understanding.

1.1 General

Majority of the people prefer burnt bricks for the construction purpose which emits huge quantity of CO_2. The usage of environmental friendly, structurally sound and inexpensive materials was used in the ancient time. The stabilized bricks are the one which have a low embodied energy of 0.42 MJ/kg and low carbon foot print (Nithiya, et al., 2016).

Bricks are widely used in construction of buildings and other infrastructural facilities. Bricks are produced using clay and sand as raw materials and burnt in kiln at high temperature of 900 to 1,000°C. It is one of the primary building materials known to mankind. Over time, bricks have appeared, gained prominence, and lost importance and then come to forefront with various styles of architecture. Burnt bricks were used in ancient India, Babylon, Egypt and Roman Civilizations (www.shodhganga.inflibnet.ac.in). They are still being used as filler materials for frame work structures as well as to construct load bearing structures. The processes of making a brick traditionally are material tampering, moulding, drying, firing and sorting (Figure 1.1).

Brick production is highly concentrated in four countries such as China, India, Pakistan and Bangladesh (Ellen Baum, 2010). India is the second largest brick producer after China. Annual brick production in India is 240-260 billion and clay consumption is around 500 million cu.m. CO_2 emission from these clay productions is 66 million tons (www.cseindia.org/dve/aad2015).

Figure 1.1 Process of making bricks

In general, the raw materials for production of bricks are clay and sand, which requires considerable amount of energy in quarrying them. Clay quarrying adversely affects the landscape and produces some waste material. Bricks are burnt in intermittent kilns or continuous kilns (Figure1.2). The kiln firing consumes significant amount of energy and releases huge quantity of green-house gases.

Figure 1.2 Kilns for burning bricks

On the other hand, clay and sand are depleting resource (Figure 1.3) and alternative materials and methods without firing to produce bricks may help in protecting the environment. Burnt clay bricks are being used extensively in India and which is the most important building material in the construction industry. Even though burnt bricks have better compressive strength, lower water absorption and less vulnerable to weathering, the non- burnt bricks are environmentally friendly eco bricks without consumption of depleting resources and having low embodied energy.

Clay bricks available in certain region are of poor quality having lower compressive strength, higher water absorption, high efflorescence etc., which forced the researchers to try for other materials with better properties and lower the manufacturing cost .

Figure 1.3 A view of clay mining

Along with clay, sand is an essential commodity in making bricks. Sand being natural resource which is of depleting in nature, so the sustainability is the main criterion in today's scenario, posing a challenge not only to construction industry but also for entire infrastructure industry. Many of the states in India have banned sand mining or restricted the sand quarrying operations. From the stage of quarrying the raw materials to till the completion of project, results in stripping of the mother earth for the use of exhaustible resource and has caused adverse effect on the environment. It has resulted in the acute shortage of fine as well as coarse aggregate, urging to explore the alternative material for partial replacement for sand and other construction materials without compromising the quality, economy and environment. In such case, the use of any industrial waste in the construction results in reduced use of natural resources.

Other types of bricks are also used in construction depending on the requirement. Sand-lime bricks are calcium silicate bricks, which are mixtures of sand and hydrated lime pressed in moulds and cured in a high pressure steamed autoclave. Concrete bricks made of mixtures of cement, sand and aggregates vibrated in moulds and steam cured. Fly ash clay bricks in which fly ash is used along with clay. In all these types of bricks, sand or clay are used which can be replaced by industrial waste.

The industrial waste always causes pollution and their disposal is a problem for the concerned authorities because either they occupy lot of space for storage or they pollute the media in which they are disposed. Mining Industry is one source of such waste generation. Mine waste available after the extraction of useful mineral as an alternative for construction materials.

Among the various minerals mined in India, iron ore is the largest in quantity. Generally iron ore mining is done using surface mining method (Figure 1.4). This ore is normally rich in iron oxides and vary in colour from dark grey, bright yellow and deep purple to rusty red. The iron is usually found in the form of magnetite, hematite, goethite and limonite.

Figure 1.4 Aerial view of mining area

The world reserves of iron ore are estimated to be around 170 billion tonnes. In terms of iron content, the iron ore reserves are estimated to be around 84 billion tonnes. In 2017, the world production of iron ore was 3,332 million tonnes as against 3,317 million tonnes in the previous year. China (37%), Australia (27%), Brazil (13%), India (6%) and Russia (3%) were the principal producers. These five countries accounted for about 86% of the world production of iron ore. The world production of iron ore is provided in Table1.1 (Indian Mineral Yearbook 2018, Iron Ore).

Table 1.1 Major iron ore producing countries in the world

Rank	1	2	3	4	5	7	6	8
Country	China	Australia	Brazil	India	Russia	South Africa	Ukraine	USA
Iron Ore production, Million Tonnes	1229	885	436	201	95	75	61	46

The total recoverable reserves of iron ore in India are about 22,487 million tonnes of hematite and 10,789 million tonnes of magnetite spread over Chattisgarh, Madhya Pradesh, Karnataka, Jharkhand, Odisha, Goa, Maharashtra, Andhra Pradesh, Kerala, Rajasthan and Tamil Nadu. Iron ore is produced at present only in some of these states. In 2017-18, about 154.60 million tonnes iron ore was consumed in various industries like Iron & Steel, Sponge Iron, Ferro-alloys, Alloy-steel, Coal Washery and Cement (Indian Mineral Yearbook 2018, Iron Ore).

Iron ore is being beneficiated around the world to meet the raw material requirements of the iron and steel industries. Specific beneficiation process is selected for optimum product extraction depending on the nature of the gangue and its association with the ore structure. The prime function of beneficiation of the iron ore in India is to improve the content of extracted iron and reduce the Al-Si content of the finished iron. The beneficiation of Iron ore proceeds mainly from washing, sizing by classification, jigging and magnetic separation.

The advantage of washing is to impact better handling properties to the ores, particularly the removal of fines, which becomes sticky in rainy season and may pose problems during transportation. After beneficiation, once silica and aluminum bearing metals are removed by washing, rejected portion of iron ore may include coarse and fine particulates in the wash water forming slurry known as wet tailings. All washing plants in India utilize ponds for disposal of tailings (Figure 1.5).

Figure 1.5 A view of tailings pond

The current mining methods generate lot of fines and the significant quantity of slimes about 18-25% of Runoff Mine (ROM) generated during wet processing of the high grade iron ore. In earlier days, washing methodology was adopted to discard the slimes as well as fines containing Fe value between 45-55% and have added 10-15Mt every year as tailings. The cut off fixed by Indian bureau of mines is 45% Fe (Anand and Omendra, 2016).

The waste/ tailings that are ultra fines or slimes, having diameter less than 150µm, are not useful and hence are discarded. In India approximately 1,500-2,000 million tons of such mined ore is lost as tailings. The safe disposal or utilization of such vast mineral wealth in the form of ultra fines or slimes has remained a major unsolved and challenging task for Indian iron ore industry (Mohanty, et al., 2010).

The disposal of these tailings is the major herculean task demanding high cost for the steel plants. Such waste materials pollute the environment and arises lot of issues connected to its storage and handling. The waste produced during mining, requires a large area to dump, which also causes dump stability problem. The waste produced during processing, called as tailings requires dams to store them. The Iron Ore Tailings (IOT) have many adverse impacts on the environment like pollution of ground water, soil erosion, loss of biodiversity, soil contamination, infertility of soil, acid mine drainage etc. The use of such tailings in the construction material has double benefit of reduction in the cost of the product and safe disposal of tailings safeguarding the environment. With IOT bricks, tailings storage & disposal can be avoided. Land requirement for tailings dam can be avoided. Lot of environmental problems in handling the IOTs can be reduced. One such usage can be in manufacture of building bricks and other value added products without burning of solid fuel, which helps in reduction of CO_2 emission and saves natural resources like sand and clay.

The bricks made of iron ore tailings (Figure 1.6), will have higher density because of iron content, which needs to be reduced without hampering the required compressive strength and other physiochemical properties.

Figure 1.6 Bricks with IOT, sand and cement

Any structure designed intelligently and responsibly aspires to be as light as possible. The function is to support live loads. The dead loads of the structure itself are a necessary evil. The smaller the ratio between a structure's dead load and the supported live load, the lighter the structures are. From an ecological, social and cultural perspective, light weight structures have never been more contemporary and necessary than today. The use of bricks as void filler in the framed structure has given rise to the concept of reducing the dead load in the buildings. Hence, a light weight additive to be added to reduce the density. Perlite is one such additive which has very low density of around 60 kg/m^3, which can be used as additive to reduce the weight of bricks.

Perlite is an amorphous volcanic rock that has relatively high water content, typically formed by the hydration of obsidian. It occurs naturally and has the unusual property of greatly expanding when heated sufficiently. It is an industrial mineral and a commercial product useful for its low density after processing. Perlite softens when it reaches temperature of 850-900^{0}C. Water trapped in the structure of the material vaporizes and escapes, and this causes the expansion of the material to 7-16 times of its original volume (Samar, 2016).

Unexpanded perlite has a bulk density around 1100 kg/m^3, while typical expanded perlite has a bulk density of about 30-150 kg/m^3(Samar, 2016). Because of light weight and better insulating characterization of perlite, it is used in light weight concrete, loose fill masonry insulation, chimney linings etc. The use of perlite in bricks may act as density controller and will impact many other advantages like heat insulation, light weight, acoustic insulation properties etc.

Energy consumption has been increasing rapidly worldwide due to strong growth in population and industrialization. Buildings are responsible for about 40% of total energy consumption and one third of green house emissions in the world. Pure thermal performance of building envelope structure is the main cause of energy consumption in buildings. In a typical house, external walls account for approximately 30% of total heat loss which requires an effort to improve heat insulation performance of each wall components (Arici, 2015). So, perlite bricks can be used in the walls to reduce the heat transfer through bricks and the use of perlite in the bricks is an initiative to green building concept having long term benefit of sustainability.

The aim of this research is to characterise and identify sustainable and greener development by adding mine wastes such as iron ore tailings and perlite in bricks for building and construction projects to ensure economic and environmental sustainability.

1.2 Problem Statement

To find the optimum percentage use of IOT replacement with sand in combination with an optimum percentage of perlite, keeping in view the required density, strength requirements and lower thermal conductivity of bricks

1.3 Objectives of the Research

In an attempt to identify the best and feasible reuse options for mine tailings and perlite in bricks for sustainable development, and to achieve the aim stated above based on the problem statement, the following are the specific objectives of the research work

a) To find the optimal proportion of IOT, perlite and cement to achieve the optimum density, strength requirements and lower thermal conductivity based on water absorption, thermal conductivity and compressive strength tests.

b) To conduct a pilot scale study by construction of a model room with IOT and perlite bricks based on the laboratory scale results.

c) To assess the economic feasibility of the bricks with IOT replacement and perlite addition.

1.4 Structure and the Organisation of the Thesis

The research work consists of literature review, carrying out field investigations in different types of bricks, construction of brick model rooms, generating the laboratory and pilot scale data and analyzing the same. This thesis is organized as following chapters.

Chapter 1: Introduction

Chapter 1 Introduces the use of the non fired clay brick as a masonry building unit, types of bricks used in construction, use of mine wastes and its environment sustainability. Also, it includes a description of research importance, scope, objectives, methodology, and the report organization.

Chapter 2: Literature Review

It is the general overview of significant and detailed literature review which is relevant and current to this study. This helped to identify the gaps in literature and what is needed to be done in order to close the gap.

Chapter 3: Experimental Investigations

A methodology was developed through practical laboratory investigations to determine the physical properties and chemical composition of iron ore tailings (IOT), sand, cement and perlite. This chapter also involves the experimental investigations such as determination of various properties of finished bricks like unconfined compressive strength (UCS), durability, density, water absorption, thermal conductivity, etc. A pilot scale study is carried out to analyse masonry building to assess the thermal efficiency and the variation of temperature induced in a structure under different intervals of time.

Chapter 4: Results and Analysis

It gives the results and analysis of all tests conducted in laboratory and in pilot scale. It provides the outcome after investigations and analysis of the influence of different parameters on brick properties. The findings of the study along with the discussion are presented here.

Chapter 5: Conclusions and Recommendations

It outlines the conclusions from the previous chapters and spells out the contribution to knowledge added to the literature as a result of this research. This chapter also uses the conclusions to suggest potential future research path as a secondary consideration to this primary research.

CHAPTER-2

CHAPTER – 2

REVIEW OF LITERATURE

More than 100 research resources were reviewed thoroughly to compile the literature review related to the chosen research area. A brief review is presented about the use of Iron Ore Tailings as a partial replacement of fine aggregates in the bricks. Many studies were conducted to enhance the insulation of buildings by reducing the thermal conductivity using different materials like perlite and techniques.

The current trend all over the world is to utilize the treated industrial by-products as raw material in the construction, which gives an eco-friendly solution to waste disposal. To achieve this objective, intensive efforts are under way for effective utilization of industrial by-products particularly from mining and mineral industries. The role of additives will enhance the physico mechanical properties of the materials, adhering to standard recommendation to the construction. The main aim of this section is to present an overview of research work carried out by various researchers in utilization of Iron Ore Tailings and Perlite.

As per Indian Standard code IS 1077:1992, the size of brick should be 230mmX112.5mmX75mm for construction purpose and should have a compressive strength of 3.5 N/mm^2 of burnt clay bricks and water absorption shall be less than 20%.

2.1 Iron Ore Tailings in Construction and Manufacture of Bricks

Clay is the main raw material for brick manufacture. Clay should exhibit some specific properties and characteristics for Civil Engineering applications. Clay must have sufficient moisture content and its air dried characteristics to maintain its shape after it is formed need to subject to optimum temperatures during firing and clay particles must fuse together.

The conventional method of making bricks causes serious environmental contamination, global warming, emission of green-house gases (GHG), smog etc. Furthermore, energy as fuel and electricity showed a drastic consumption during the traditional manufacturing of bricks. As a result, lot of trees are cut in forests to use the wood as source of energy in firing stage of bricks production. Hence, recycling the wastes in the brick production appears to be viable solution for not only to environmental pollution but also economical option to design of green buildings.

Giri and Krishnaiah (2018) reviewed on the utilization of waste materials for manufacturing of bricks to provide a potential and sustainable solution for the eco-friendly environment. Certain bricks are made without firing which is an advantage over other method of manufacturing of bricks in terms of low embodied energy material. It also offers a solution to the problem of waste disposal as well as eco-friendly environment in construction industry.

Use of iron ore tailings to produce non fired bricks, not only can realize zero waste of IOT, but also would offer a new raw material for building industry, which is more effective resource recovery alternative. In recent years, utilization of IOT has got much global attention especially in Civil Engineering Construction. This practice can help to reduce the emission of greenhouse gases: by avoiding the emission of virgin Engineering materials, providing cheaper alternative materials for building and constructions and also for natural resource conservation (Chen, et al., 2011).

The iron ore tailings contain high percentage of silica. The high silica content in the IOT is considered favourable in terms of the property and the raw material requirements for the production of ceramic tiles and bricks. They are unwanted material of economic interest from the gangue or wastes of iron ore tailings and have other useful properties such as self-cementing characteristics which remove the necessity of adding cement when it is being used to fill mined out areas and for slimy nature and it contains large quantities of sulphides which oxidizes on contact with the air to form hard cement like crust.

2.1.1 Iron ore tailings as replacement for sand in bricks

Hammond (1998) critically reviewed the use of mining and quarrying waste as building material. The availability, distribution and uses of waste from many mining countries of the world were discussed. The use of mining waste materials as concrete aggregates for the purpose of construction, production of brick and tiles, cement, pozzolana and pigments for paints were identified. It was stressed that, by using waste materials, natural resources will be conserved, energy will be saved and environmental pollution will be reduced.

Das, et al., (2000) also described a new development in managing iron ore tailings by converting them into value added products such as ceramic floor and wall tiles for building applications. They reported that iron ore particles below 150μm in size were discarded as waste tailings. They also tested constituents of the tailings from different locations and their mixture using standard techniques like XRD (Siemens D 500) with Ni filter and Cu (Kα) radiation. The result of the test is presented in the Table 2.1. The iron ore tailings were found to contain high percentage of silica as can be seen in Table 2.1. The high silica content in the iron ore tailings is considered favourable in terms of the property and the raw material requirements for the production of ceramic tiles. The study concluded that iron ore tailings up to 40% by weight can be considered for use as a part of raw materials for ceramic floor and wall tiles due to its high silica content. The ceramic tiles from the iron ore tailing materials were found to be superior in terms of scratch hardness and strength. The new tiles from the iron ore tailings maintain most of the other essential properties as the conventional raw materials used for ceramic tiles. The application of iron ore tailings in the ceramic tiles production was also found to be cost effective in comparison with the usual traditional clay for ceramic tiles production.

Table 2.1 Constituents of iron ore tailings from five locations and their mix (Das et al., 2000)

Samples in weight, %						
Constituents	D1	D2	D3	D4	D5	Dmix
SiO_2	39.40	42.94	40.06	63.32	60.42	51.12
Al_2O_3	1.36	1.42	1.33	1.37	1.42	1.22
Fe_2O_3	55.61	52.05	55.32	32.31	34.81	44.36
CaO	0.12	0.08	0.25	0.36	0.33	0.22
Loss of ignition	3.42	3.40	2.91	2.56	2.33	2.95

D1, D2, D3, D4 and D5 are different locations.

Kumar, et al., (2006) investigated the use of fly ash, blast furnace slag and iron ore tailings in the production of floor and wall tiles. Different percentages of iron ore tailings were tried with fly ash and blast furnace slag and proved fly ash, blast furnace slag and iron ore tailings in suitable combination in ceramic tiles will improve their qualities including scratch hardness more than six on Mohr's hardness scale and flexural strength more than 25MPa.

Ullas, et al., (2010) determined water absorption of stabilized mud blocks (SMB) replaced by IOT, is more but well within limits i.e. 12-15% because of increase in voids due to higher fine fraction. There is no linear expansion noticed when IOT is used. There is negligible fall of wet compressive strength of brick, when IOT is used and it is only difference of 0.25MPa when 100% sand is replaced by IOT.

Yongliang, et al., (2010) determined the microstructure of fractured surface of the dried specimen using iron ore tailings, cement, sand and gypsum without firing shown compact microstructure and sheet like appearance of phyllosilicates and after firing to 1000^0 C for 2 hours; clear evidence of vitrification which was the typical grain and bond microstructure and crystalline phase were embedded in glassy matrix forming strong entirety, which promoted the strength of the brick. The compressive stength of finished brick was 15.9 MPa with ratio of tailings: cement: sand: gypsum = 78:10:10:2 with 15% forming water content (Table 2.2). The strength of bricks decreased when IOT content was over 78%. Microstructure of the brick revealed the compact microstructure of sheet apperance of phychorilicates and the granule silica and hematite.

Table 2.2 Properties of non-fired tailing bricks (Yongliang, et al., 2010)

Inspection items	MU15 class standard specification (JC/TA22-2007)	Non – fired tailing bricks
Average compressive strength, MPa	≥ 15.00	15.90
Minimal compressive strength, MPa	≥ 12.00	14.40
Compressive strength after freeze – thaw cycle, MPa	≥ 12.00	13.67
Mass loss after freeze – thaw cycle, %	≤ 2.00	2.00
Drying shrinkage, %	≤ 0.06	0.05
Water absorption, %	≤ 18.00	17.38

Ravi Kumar, et al., (2012) studied replacement of IOT for cement in bricks and determined compressive strength, studies revealed that upto 15% of replacement of IOT will give higher compressive strength and replacement between 15% and 25% will give lower compressive strength.

Studies conducted by Mangalpady (2012) revealed that the chemical composition of the tailings is directly dependent on the composition of the ore and mentioned about the suitability and reliability of IOT in the manufacture of pavement blocks. By using sand and IOT, few reference mixes with cement, jelly, dust and baby jelly with different mix ratios were prepared. It was found that compressive strength of IOT based mix was higher than the reference mix and the workability has improved upto 10% replacement of cement and IOT has pozzolanic property.

Carrasco, et al., (2013) studied on compression performance of walls of interlocking bricks made of iron ore by-products and cement. It deals with technical evaluation of the performance of walls constructed with interlocking bricks of iron ore by-products and cement under simple compressive loading (Figure 2.1). Three walls with dimensions of 150 cm width, 240 cm height and 15 cm thickness were built and tested. Testing was carried out according to the specifications of Brazilian standards. The first fissures arose with a stress of 0.56 MPa, corresponding to only 3.8% of the rupture stress of the brick alone. Horizontal displacement was negligible in all the walls and buckling was not observed. Rupture of the walls was through crushing; micro fissures appeared first and evolved into fissures and then transformation into cracks. After generalized occurrence of cracks, rupture occurred. This behavior was similar to that of the bricks. Compressive load tests were also performed to determine the strength of the brick, of the prism (two overlaid bricks) and of the mortar. Results showed high compressive strength of 14.57 MPa for bricks, 9.82 MPa of the prisms and 25.2 MPa of the mortar. The walls showed good mechanical strength of 2.05 MPa, which represents 14% of the brick strength. Deformations were high, with axial deformation modulus of 420 MPa, which indicates a flexible behavior of the wall. Although the wall is flexible, the fissuration stress is relatively high, indicating excellent performance of the wall. Another very positive aspect is that this stress is only 13.6 % of the compressive strength of the wall and 1.9% of the brick, which indicates that there is a very large strength reserve.

Figure 2.1 Overview of wall building process (Carrasco, et al., 2013)

Huang, et al., (2013) developed green engineered cementitious composite (ECC), replacing cement by less reactive iron ore tailings, reduced the matrix fracture toughness. Engineered cementitious composite will be of less compressive strength when replacement ratio is beyond 40% by IOT for cement. Mechanical properties and material greenness of ECC containing various proportion of IOT are investigated. IOT used in powder form with intention of enhancing the environmental sustainability of ECC. The ECC developed in this study, with a cement content of 117.2-350.20kg/m^3 has tensile ductility of 2.3-3.3%, tensile strength 5.1-6MPa and compressive strength of 46-57MPa after 28 days. The replacement of cement with IOT will result in 10-32% reduction in energy consumption and 29-63% reduction in carbon dioxide emission compared with typical ECC.

Chuanmeng, et al., (2014) investigated the manufacture of light weight aggregate by the mixture of the low silicon iron ore tailings, fly ash and powdery quartz sand. The SiO_2 content in the iron ore tailings is lower than the requirements for light weight aggregate, while the fluxing content in the iron ore tailings is higher than the requirement for light weight aggregates. So fly ash and powdery quartz sand were used as additives in this study to adjust the chemical composition of the iron ore tailings. The mixture of all showed good bloating behavior during sintering. The loose bulk density and the apparent density of the products were well below the required density for light weight aggregates.

Light weight aggregates can be formed in a ceramic process in which materials that have the ability to expand are rapidly heated at high temperature. Manufacturing of light weight aggregate using iron ore tailings is not only a useful alternative to the extraction of natural aggregates, but also helpful in recycling of the industrial waste.

Francis, et al., (2014) investigated the strength of the geo polymer bricks made from iron ore tailings (IOT) and sodium silicate (Na_2SiO_3), including UCS, durability and electrical resistivity. The strength of the geo-polymer bricks made from iron ore tailings with sodium silicate solution is influenced greatly by the curing temperature. The UCS increased as the curing temperature increased to a certain optimum point (80^oC), then the UCS decreased as the temperature increased further. The optimum base parameters for the production of the geo-polymer bricks are sodium silicate solution content of 31%, initial setting time of 15 min and curing temperature of 80^oC (Table 2.3). The electrical resistivity of geo-polymer bricks is lower than the commercial clay bricks due to the higher iron content associated with IOT. However, the electrical resistivity of the geo-polymer bricks is still high enough to be used for building construction.

Table 2.3 Various properties of the bricks at different curing times (Francis, et al., 2014).

Curing conditions	Electrical resistivity, kΩm	Compressive strength, MPa	Water absorption, %	Density, kg/m^3
Commercial clay brick	1080	25.72	7.70	2180
Tailings brick at 1 day curing	456	19.18	8.72	2080
Tailings brick at 3 days curing	642	34.00	8.41	1990
Tailings brick at 7 days curing	>682	50.35	9.00	2130

Jemish, et al., (2014) conducted an experimental study on manufacturing of iron ore waste bricks made of iron ore fine wastes. Mixture was made of iron ore waste; sand and cement with four different proportions and attempts were made to find the suitability of the bricks. In this study, bricks with iron ore waste substituted for sand showed better compressive strength without much water absorption. The mixture made of cement, sand and iron ore waste with the ratio 30:30:40 and with 28 days curing period attained a compressive strength of 42.95 MPa and water absorption of 2.42%. This property met the requirement of IS 2180-1988 specification for heavy duty burnt clay building bricks in terms of compressive strength and water absorption.

Kumar (2014) studied on utilization of iron ore tailings as replacement to fine aggregates in cement concrete pavements. In this study, Iron Ore Tailings (IOT) used as partial replacement to fine aggregates at levels of 10, 20, 30, 40, 50 percent and the basic material properties, strength parameters are studied. It is found that as the IOT percentage increases in the mix, workability is reduced. The cube specimens were tested in Compression Testing Machine after specified curing period for different percent of IOT replacement Mix1(10%IOT), Mix2(20%IOT), Mix3(30%IOT), Mix4(40% IOT) and Mix5(50%IOT) and for normal concrete mix. At 40 percent replacement level for 28days, compressive strength is more than the reference mix (Normal concrete mix) and other replacement percentage mixes (Figure 2.2). Flexural strength is observed maximum for reference mix. Quality of concrete mixes is found good from Ultrasound Pulse Velocity test. Flexural fatigue analysis is carried out on mix with 40percent. IOT replacement at stress ratios 0.65, 0.70 and 0.75 compared with IRC model for number of repetitions using log normal distribution. Up to 0.7 stress ratio, it showed more number of repetitions than IRC and at higher stress ratio mix with IOT achieved failure earlier.

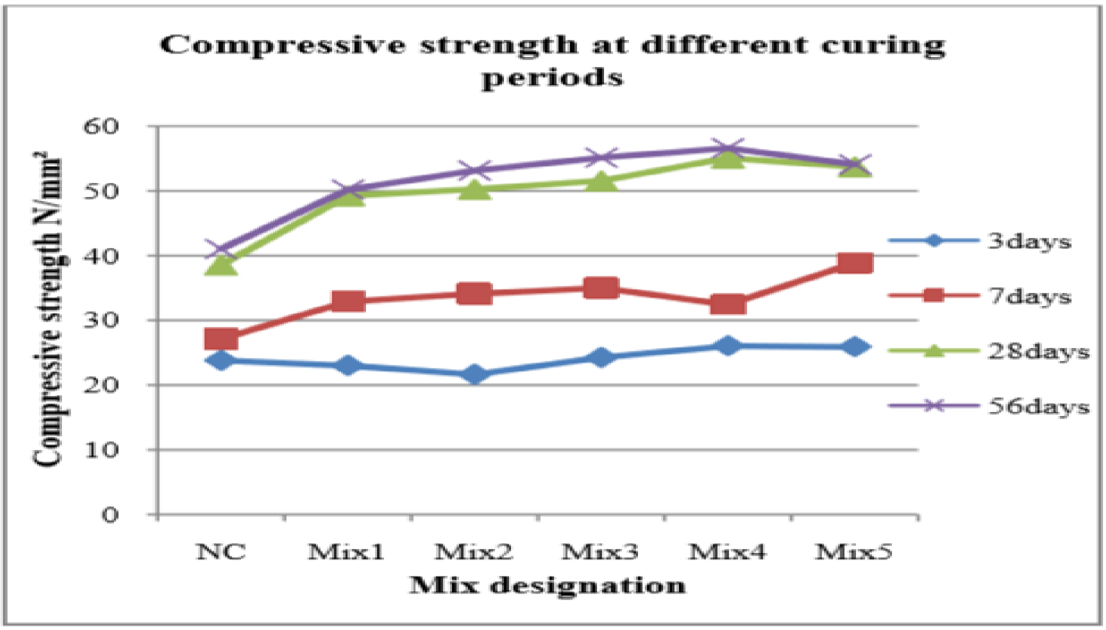

Figure 2.2 Compressive strength development of different mixes (Kumar, 2014)

Prahallad, et al., (2014) studied on stabilized Iron Ore Tailings (IOT) blocks showing an increasing trend in the erosion resistance with increase in curing period. Stabilized IOT blocks showed decrease in liquid absorption with increased stabilizer percentage and curing period i.e 1.35% on 21days curing of 7% cement stabilization. Maximum dry compressive strength of IOT blocks with 7% cement stabilization on 21days curing is 8.5MPaand the ratio of wet to dry compressive strength lies between 0.50 and 0.73.

Prem Kumar, et al., (2014) experimented by replacing 0%, 10%, 20%, 30%, 40%, 60%, 80% and 100% of sand by IOT. There is an increase in the compressive strength due to sand replacement by iron ore tailings. The maximum increase in compressive strength for about 40% of sand replacement and there is no reduction in flexural strength of reinforced concrete beams.

Ugama and Ejeh (2014) studied the suitability of IOT as fine aggregate for replacement for sand in masonry mortar and found compressive, tensile and flexural strength of 36.95MPa, 1.76 MPa and 5.73MPa respectively for optimum level of 20% of IOT replacement.

Abdulrahman (2015) produced sand concrete blocks with mix ratio of 1:6 (one part of cement to 6 parts of sand) where sand portion was replaced by IOT at different percentages like 10, 20 and 30% at 28days curing, compressive strength approached the recommended strength for 230mm blocks and proved that there is a way for waste disposal (IOT) and development of eco-friendly sand Crete blocks.

Kshitija, et al., (2015) studied on use of iron ore tailings as a construction material. In the study IOT used as a partial replacement of the fine aggregates. In this study, 15 – 20 % replacement of iron ore tailings is recommended which can save up to 20 % of fine aggregates and thereby reducing the cost of production and also reducing pollution of environment by using IOT and marching towards sustainable construction. Concrete with iron ore tailings is a sustainable solution as it reduces sand by as much as 15% by iron ore tailings in concrete.

Nagraj (2016) has conducted exploratory study on compressed stabilized earth blocks (CSEB) utilizing various proportions of mine spoil waste (MSW) (accumulated at up steam of mining area at Sandur region, Karnataka), quarry dust and stabilizers (cement and lime).

Mine spoil waste utilized in three possibilities 30, 40 and 50% with cement and lime as stabilizer in two combinations like 6% cement + 2% lime and 8% cement + 2% lime in CSEB blocks. It was observed that wet compressive strength for any combination of admixture is more for blocks prepared with 40% MSW, which indicates these blocks can be effectively used as eco-friendly bricks in construction industry.

Shreekant et al., (2016), carried out studies on utilization of iron ore waste in brick making for construction industry. He made an attempt to examine the possibility of making non-fired bricks from iron ore waste with some additives like cement and fly-ash. Each of the additives were mixed with iron ore waste (IOW) in different ratios and different sets of bricks were prepared. The prepared IOW bricks were cured for 7, 14, 21 and 28 days and their respective compressive strength and percentage of water absorption were determined (Figure 2.3). The results showed that IOW bricks prepared with 9% and above cement and with 28 days of curing are suitable for brick making and meet the IS specifications. It was also observed that the weight of the prepared bricks with 9% cement with 28 days of curing varies between 2.35 and 2.45 kg whereas the weight of compressed fire clay bricks varies from 2.80 to 2.89 kg. Results also shown that the cost of bricks prepared with cement ranging from 9 to 20% is comparable to that of commercially available compressed bricks.

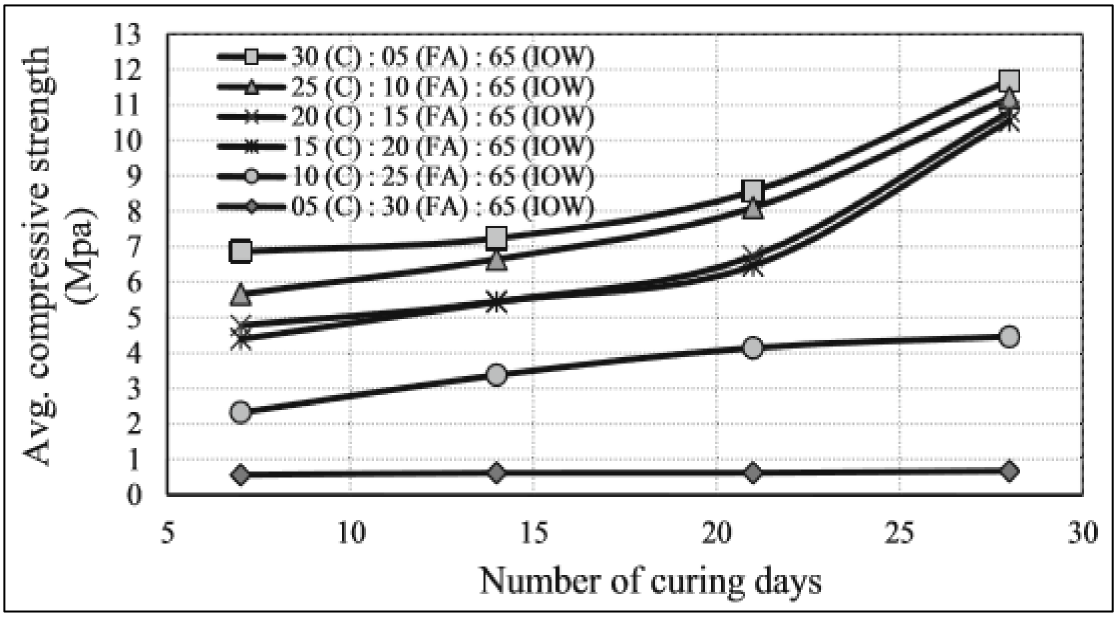

Figure 2.3 Compressive strength vs number of cuing days (Shreekant et al., 2016)

Yisa, et al., (2016) investigated the compressive strength of the laterite bricks with iron ore tailings of weight 250gm, 500gm and 750gm mixed with fixed quantity of soil i.e. 2,000gm from Zaria of Nigeria and arrived at a conclusion that compressive strength of laterite mix containing varying weight of IOT had higher strength value of 27 MPa when compared with only laterite which has compressive strength of 14 MPa for 7 days curing. Compressive strength of laterite bricks with IOT mix increased with increase of IOT content compared to laterite.

Likith et al., (2017) studied manufacturing of building blocks by utilizing of iron ore tailings. The study presents that substitution of iron ore tailings and quarry dust shows better compressive strength without much change in water absorption. It is also revealed that the mix with tailings has the highest compressive strength for 28 days curing. By using these wastes instead of conventional materials, not only preserves the natural precious resources, but also solves the problems of disposal of waste.

Beatryz et al., (2019) investigated on technical and environmental assessment of the incorporation of iron ore tailings in construction clay bricks. The aim of this research is to study a new alternative for reusing high-silicon iron ore tailings, by applying it in the red clay ceramic industry. For this, a mixture design of experiments was developed, using three components i.e. iron ore tailings and two clayey materials. The two clayey materials are incorporated in ranges of 0%-40% and 30%-70% (by mass). Subsequently, ten mixtures obtained from the experimental design were prepared, and cylindrical specimens were formed by uniaxial pressing. After the firing at 850^{o}C, 950 ^{o}C and 1050 ^{o}C, the properties of firing linear shrinkage, bulk density, apparent porosity, water absorption, compressive strength and microstructure behavior of the specimens were assessed. Both the mixture design of experiments and desirable function enable the determination of an optimal composition which contains 29.1% (by mass) of tailings and which meets the international standards. The brick has presented 20.94% of water absorption and compressive strength equal to 4.27MPa, providing its potential to be used in sealing masonry.

2.1.2 Energy consumption in the production of bricks

The embodied energy of the brick is the sum of all the energy required to produce the bricks, in all processes from quarrying of clay to firing of bricks. Energy inputs usually entail greenhouse gas (GHG) emissions. It decides how much brick production contributes to global warming. The embodied energy is measured in MJ/kg. A non-fired brick has the advantage of lower embodied energy and in turn lower GHG emission.

Toledo, et al., (2004) analyzed the gas release, crystalline structure and ceramic properties formed during firing of clay raw materials and extruded bricks. CO, CO_2 and NO_2 and methane emission were measured during firing cycle and found CO_2 emitted from the powder was 8,600PPM and from the extruded samples was 6,500PPM, CO emission was found to be 1,100PPM from the powder and 800PPM from the brick and with some minor emission of NO_2 and CH_4.

Micheal, et al., (2009) surveyed on the energy consumption and the greenhouse gases emission during the clay brick production in United States. Embodied energy for common clay was about 9.3MJ/brick. The greenhouse gas emission per common clay brick fired using fossil fuel was around 0.6kg of CO_2 to the atmosphere whereas; one common concrete brick emits 0.3kg of CO_2.

Gonzalez (2011) has highlighted about the environmental contamination represented by the enormous emissions of greenhouse gases (GHG) resulted in unusual climate changes as smog, acid rain and global warming. Hence, recycle the wastes in the bricks production appears to be viable solution for not only to environmental pollution but also economical option to design of green buildings. However, the chronic problem of GHG and energy consumption has not yet been tackled properly as many of the previous research works were mainly focused on recycling the waste traditionally in the bricks.

Li, et al., (2019) discussed and concluded about recycling of industrial waste iron ore tailings in porous bricks with low thermal conductivity. The results showed that sintering temperature, soaking time and milling time had significant effects on porosity, compressive strength and microstructure of the porous tailing ceramics. Extending soaking time, meanwhile decreasing sintering temperature could effectively improve the compressive strength of sample with similar porosity. The thermal conductivity of the porous tailing bricks could reach the lowest value of 0.032W/mk with the porosity of 89%. The thermal conductivity of samples with varied porosity is comparable with the calculated values deducted from the universal model, which makes a good description of the relationship between porosity and thermal conductivity.

2.2 Perlite as Density Controller

Perlite is naturally occurring Alumino – Silicon amorphous volcanic rock. Raw perlite when heated to temperature above 870^0C expands and transform into a cellular material of low bulk density. This expansion process is due to the presence of two to six percent combined water in the crude perlite rock. Upon rapid heating, water held within the perlite vaporizes and creates bubbles in the heated softened rock. During this process, perlite expands upto 15-20 times of its original volume and produces frothy like micro structure (Figure 2.4). This microstructure gives the material a set of favorable property such as better insulation properties, low density and high porosity causing expanded perlite as one of the most popular light weight mineral filler (Sengul, 2011).

Figure 2.4 Use of expanded perlite in bricks

Bulut (2010) stated that perlite has chemical inertness, fire resistance and high absorption of sound. All these properties make perlite a usable material for many applications. The expanded perlite can be used in the construction industry and horticulture market and as a filter aid and filler. This light weight filler is used as insulating cover on the surface of the molten metal to prevent excessive heat loss during delays in pouring, to top of ingots, to reduce piping and decrease lamination; to produce refractory blocks and bricks or simply as fillers and in several important foundry applications.

The only deposit of perlite in India is located in the Village Patanvav, Rajkot district, Gujarat. It is found to occur in Osam Hill in the form of discontinuous sill. The total resources of perlite as per National Mineral Inventory (NMI) database, based on UNFC system as on 1/4/2015 have been estimated at 2.41 Mt, out of which 12% are high grade, 12% medium-grade, 6% low-grade and the remaining 70% fall under unclassified category (Indian Mineral Yearbook 2017).

The world production of perlite in 2016, in respect of principal countries was 3.49 million tonnes as compared to 3.61 million tonnes in the preceding year. China, Greece, USA and Iran are the leading producers. As per the Ministry of Commerce, the total imports of Perlite during 2014-15 and 2015-16 was 41.53 & 43.57 tonnes respectively (Indian Mineral Yearbook 2017).

One of the main problems associated with the production of expanded perlite is formation of relatively large quantities of fine fraction (about 5-10%) with a particle size below 200μm. The resulting lightweight waste due to a large specific surface area and dustiness is very difficult to dispose, especially in dry conditions and so far did not find effective applications. Expanded perlite is fire, heat and chemical resistant material that have porous structure. Porosity is determined as the average ratio between volume of pores and total volume of perlite grains. Porous structure gives perlite volumetric and surface absorption capability. To prevent water pollution and to ensure insulation, water absorption is involuntary, because pores filled with water increase heat conductivity. Porous structure gives perlite surface absorption and light weight property. The unit weight of perlite depends on gradation and expansion. The heat conductivity of dry perlite that has unit weight of 90 kg/m^3 is calculated as 0.04 W/mK at 24^{o}C according to dry unit weight method. Perlite materials have advantage on sound absorption and insulation. Chemically, perlite ore consists of SiO_2, Al_2O_3, and lesser amounts of several metal oxides (sodium, potassium, iron, calcium, and magnesium) and therefore can be an attractive addition in many of the building materials like concrete, brick etc., because of its excellent insulation properties and relatively high compressive strength despite a very low bulk density (Sarmar, 2016).

2.2.1 Use of perlite in bricks

Demir and Orhan (2004) investigated on the production of construction bricks with perlite addition. The production of light building brick with adding of perlite into the clays was aimed. The study of chemical, mineralogical and thermal analysis was carried out on perlite brick. In order to get comparable results, the materials produced to test were added into the brick clay which is by weight: A: 0 % perlite, B: 2.5 % and C: 5% expanded perlite (EP). Test specimens were produced by vacuum extrusion with a press having cross-section of 75x40 mm, 100 mm length and 35 % perforation volume. The samples were tested by using the standard test methods and compared with the specifications and evaluated. Porosity and water absorption values increased in the perlite addition series. Thermal conductivity values of sample drastically decreased with increase in amount of expanded perlite (EP). Compressive strength with addition of 5% perlite is 8.72MPa compared to bricks without perlite 9.25MPa is less but it is higher than the standard (Figure 2.5). As a result, it was concluded that perlite addition shows a behaviour of lightweight and insulation building brick.

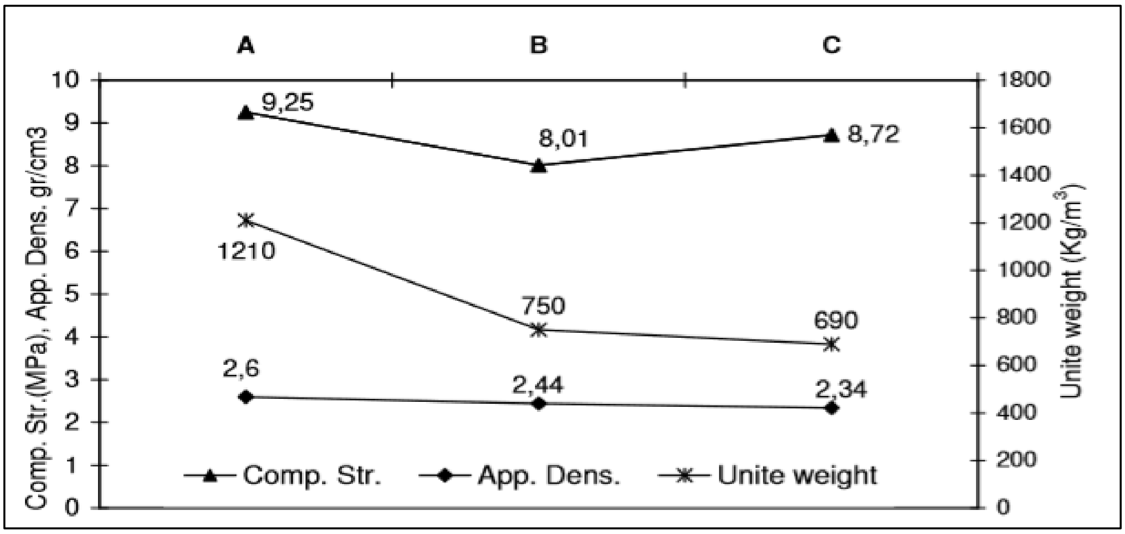

Figure 2.5 Compressive strength, apparent density and unit weight results (Demir and Orhan, 2004)

Lanzon and Garcia-Ruiz (2008) studied the influence of perlite on the fresh and hardened state of cement mortar. Water absorption, workability, mechanical strength, and sorptivity were reported. The outcomes indicated that water absorption, sorptivity, and mechanical strength induced a negative effect, while water retentivity and workability have improved generally.

Figen et al., (2010), carried out a research on development of the insulation materials from coal, fly ash, perlite, clay and linseed oil. The results showed that compressive-tensile strength of the insulation material decreased when the high fly ash ratio and high epoxidized linseed oil ratio used in the preparation of the insulation material composition. The compressive and tensile strengths varied from 10.01 to 1.107 MPa and 8.38 to 1.013 MPa, respectively. The minimum thermal conductivity of 0.313 W/mK observed for the sample made with a 60% FA/30% C/10% P ratio and 50% ELO processed at 200°C. It is increased with the decrease of ELO and FA. Results indicate an interesting potential for the coal fly ash recycling and epoxidized linseed oil renewable to produce useful materials.

Borvorn (2011) presented the results of an experimental study on the residual compressive and splitting tensile strength of autoclaved aerated concrete (AAC) containing perlite and polypropylene (PP) fibre subjected to high temperatures. Cylinder specimens were subjected to various temperature ranges of 100, 200, 400, 800, and 1,000°C. The mixtures were prepared with AAC cementitious materials containing perlite at 15%, 20%, and 30% sand replacement. The polypropylene fibre content of 0, 0.5%, 1%, 1.5%, and 2% by volume was also added to the mixture. The results showed that the unheated compressive and splitting tensile strength of AACs containing PP fibre were not significantly higher than those containing no PP fibre. Furthermore, the presence of PP fibre was not more effective for residual compressive strength than splitting tensile strength (Figure 2.6 and Figure 2.7). The 30% perlite replacement of sand gave the highest strength. Based on the results, it can be concluded that addition of PP fibre did not significantly promote the residual strength of AAC specimens subjected to high temperatures.

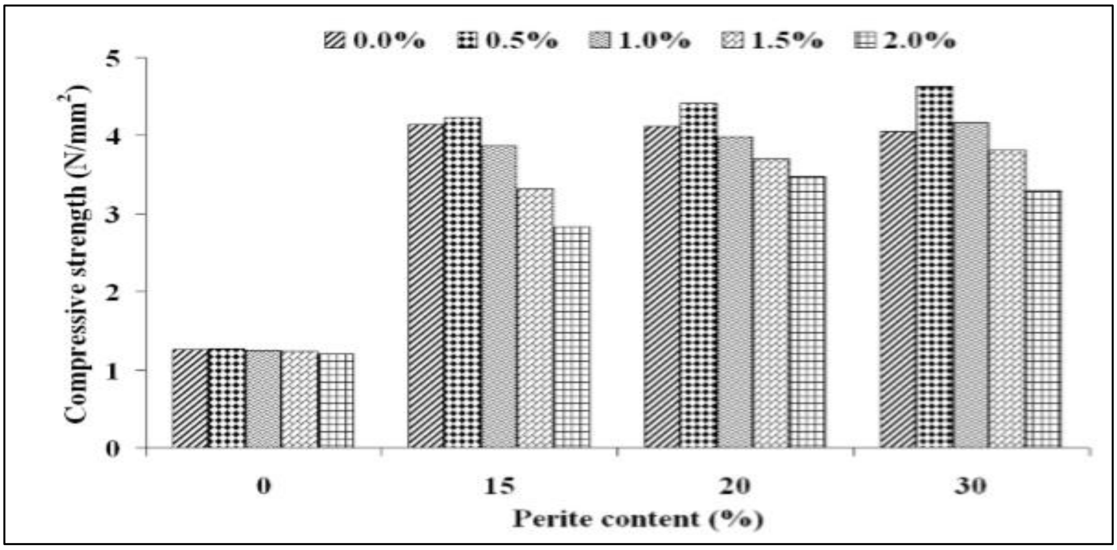

Figure 2.6 Unheated compressive strength of AAC mixed with PP fibre (Borvorn 2011)

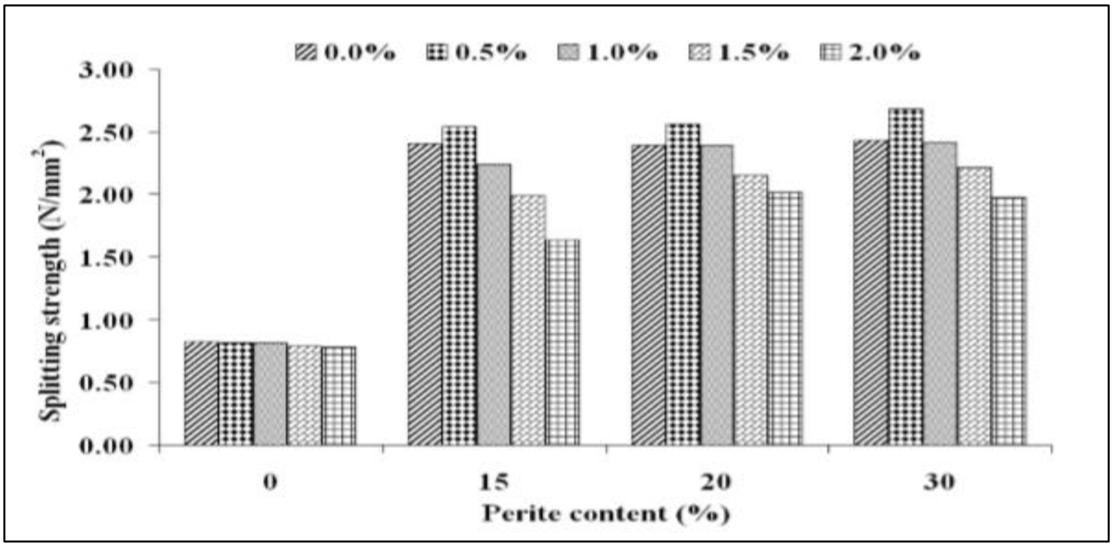

Figure 2.7 Unheated splitting strength of AAC mixed with PP fibre (Borvorn 2011)

Sengul, et al., (2011) used perlite instead of fine aggregate with various replacement ratios depending on required strength. Test results indicated the compressive strength and modulus of elasticity decreased with increasing perlite content in the concrete mixture. Moreover, water absorption and sorptivity co-efficient increased with the higher perlite contents. Replacing normal aggregate by expanded perlite reduced the thermal conductivity of the mixtures as a result of the porous structure of the perlite.

Benk and Coban (2012) studied the production of lightweight, heat insulating and water resistant bricks from lightweight aggregate like pumice and expanded perlite. The raw pumice was poured into the water and then floated aggregates were selected for the mixture. The floated pumice was dried and crushed with respect to pass through 1mm sieve. Crushed pumice was mixed with perlite borax and with blend of molasses and hardener. About 40 bricks were prepared from three types of mixtures. Each brick was fabricated by compressing 20gm of the mixture in 23mm internal diameter steel mould. The mix design containing 20% expanded perlite, the amount of mixture was diminished to 10gm. Heat treatment applied was 200^0C for 2 hours then 650^0C for 1 hour and at last specimen were cured at 825^0C for 1 hour. Results showed that the hardened molasses bonded bricks should be preferred. When 2.5% borax was not used in the mixture, considerable reduction in tensile strength of bricks was occurred by alteration of replacement ratio of perlite with pumice.

Celik and Durmaz (2012) studied the compressive strength in different cement types and dosages of concretes made by using 60% pumice and 40% perlite. In this study, it was tried to obtain bearing concrete by using the pumice and perlite aggregates in certain proportions. Different cement dosages were used in every mixture poured with portland cement and portland composite cement, the 60% pumice and 40% perlite aggregates of which were kept stable. The silica fume was added as much as 10% of cement amount in mixture. Mixtures from 200 to 500 doses were made and poured with every type of cement. The prepared samples left to water cure and their 7 and 28 days compressive strengths were determined. The test results indicated that the mixtures poured with portland cement has a higher compressive strength than those poured with portland composite cement. While the concretes poured with portland composite cement up to 500 doses can be used only insulation, the concretes poured with portland cement at 450 doses and above show the characteristics of side bearing concrete. The cement dosage increases the compressive strength in lightweight concrete poured with PC32.5.

ChaoukiSadik, et al., (2013) produced porous fire brick from mixture of clay and recycled refractory waste with the expanded perlite addition. Production of porous and lightweight bricks with acceptable flexural strength is accomplished. Expanded perlite was used as an additive to an earthenware brick to produce the pores. SEM-EDX, XRD and XRF analysis of the raw materials and the elaborated refractory were performed (Figure 2.8). Mixtures containing perlite were prepared at different proportions (up to 30% Vol.%). Apparent porosity at 1600°C was investigated with the bulk density, water absorption, firing shrinkage and flexural strength. Microstructural investigation was carried out by both natural light microscopy and polarized light microscopy. The results obtained showed that the samples tested here maintained their shape without undergoing any deformation up to 1600°C. The use of expanded perlite decreased the fired density of the bricks down to 1.55g/cm^3.

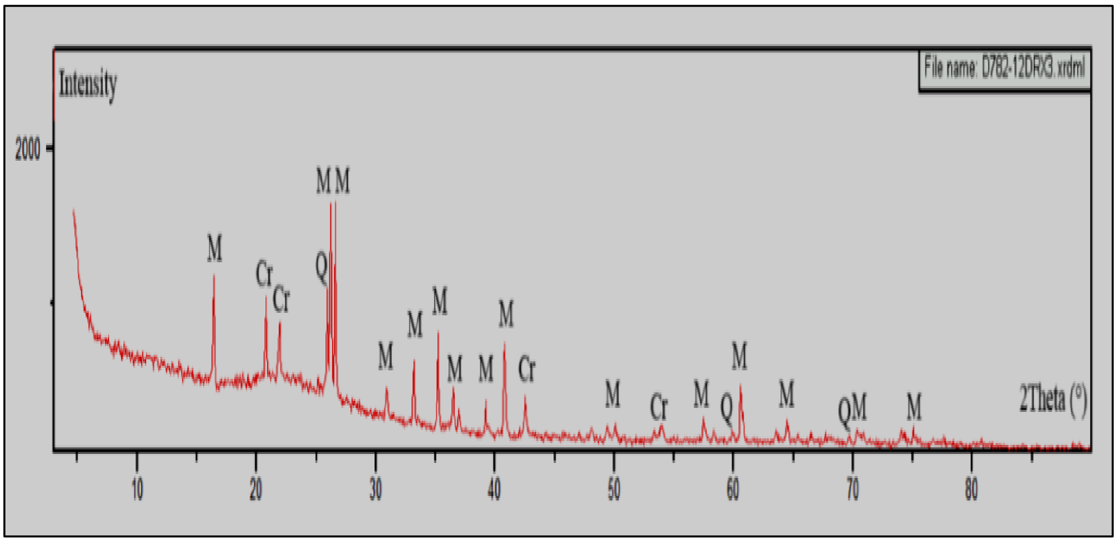

Figure 2.8 X-ray diffraction patterns of the brick manufactured from mixture and fired at 1600°C/1h (M: Mullite, Q: Quartz, Cr: Cristobalite) (ChaoukiSadik, et al., 2013)

Celik, et al., (2014) investigated the reproducibility of brick using expanded perlite aggregate as the main raw material. In additional carboxy methyl cellulose (CMC) as a chemical binder, potassium and sodium borate were used as natural binder and coal powder as an additive. Samples were cured at 400^{0}C for 2 hours. The results indicated the unit weight between 520-580 kg/m^3 and compressive strength as 23kg/cm^2. Thermal conductivity fluctuated between 0.09 to 0.123W/mk. Perlite bricks with Na or K borate averted harmful sun light and radiations by its higher neutron absorbility.

Mohajer, et al., (2014) studied on light weight refractory insulation panels on the basis of perlite 30% with chemical bonding (H_3PO_4) showed sintering behavior is the key to achieve right balance between the lower densities, which is the basis for good thermal insulation properties, good mechanical properties and durability, saving the energy that escapes from the industrial furnaces.

Mueena and Shweta (2016) summarized the study of chemical and physical properties of perlite and its application in India. The chemical composition of Perlite are: 70–75% Silicon Oxide: SiO_2, 12–15% Aluminium Oxide: Al_2O_3, 3–4% Sodium oxide: Na_2O, 3–5%

Potassium Oxide: K_2O, 0.5-2% Iron oxide: Fe_2O_3, 0.2– 0.7% Magnesium oxide: MgO, 0.5–1.5% Calcium oxide CaO and 3–5% loss on ignition (chemical / combined water) are shown in Table 2.4.

Table 2.4 Typical chemical properties of perlite (Mueena and Shweta 2016)

Element composition, %			Chemical composition, %		
Silicon	Si	33.8	Silicon dioxide	SiO_2	72.08
Aluminium	Al	7.2	Alumina	Al_2O_3	12.92
Potassium	K	3.5	Titanium dioxide	TiO_2	0.90
Sodium	Na	3.4	Iron oxide	Fe_2O_3	1.50
Iron	Fe	0.6	Magnesium oxide	MgO	0.63
Calcium	Ca	0.6	Quick lime	CaO	0.88
Magnesium	Mg	0.2	Caustic soda	Na_2O	3.76
Mica	-	0.2	Potassium oxide	K_2O	4.33
Oxygen	O	47.5	Bound water	H_2O	3.0

Unexpanded ("raw") Perlite has bulk density around 1100 kg/m^3 (1.1 g/cm3), while typical expanded Perlite has a bulk density of about 30–150 kg/m^3 (0.03-0.150 g/cm3). Physical properties of Perlite that are exploited commercially include its chemistry (Si, Al); state (alkaline, inert, and hydrated); habit (amorphous, fibrous) and physical behavior (thermal insulator, low density and porosity) — as summarized in Table 2.5.

Because of perlite's outstanding insulating characteristics and light weight, it is widely used as loose-fill insulation in masonry construction. In this application, free-flowing perlite loose-fill masonry insulation is poured into the cavities of concrete block where it completely fills all cores, crevices, mortar areas and ear holes. In addition to providing thermal insulation, perlite enhances fire ratings, reduces noise transmission and it is rot, vermin and termite resistant. Perlite is also ideal for insulating low temperature and cryogenic vessels. When perlite is used as an aggregate in concrete, a lightweight, fire resistant, insulating concrete is produced that is ideal for roof decks and other applications. Perlite can also be used as an aggregate in Portland cement and gypsum plasters for exterior applications and for the fire protection of beams and columns. Other construction applications include under-floor insulation, chimney linings, paint texturing, gypsum boards, ceiling tiles, and roof insulation boards.

Table 2.5 Typical physical properties of perlite (Mueena and Shweta 2016)

S. No.	Property	Value
1	Color	White/ Grey
2	Brightness, % GE	70-80
3	Apparent density, kg/m^3	50-300
4	Hardness index, Mohs	5.5
5	Specific Gravity	2.2 - 2.4
6	pH	6 – 8.5
7	Water absorption, % of mass	200 – 600
8	Ability to absorb oils, gram of oil per gram of Perlite	50 – 100
9	Melting point, ^oC	980
10	Burn losses (3 hours under t of 900 ^oC), %	Upto 1.5
11	Humidity, %	Upto 1.0
12	Maximum strength, MPa	Upto 6.0
13	Porosity, %	70 – 85
14	Portion of air, %	80 – 95
15	Thermal conductivity, W/mK	0.043 – 0.093
16	Thermal diffusivity, m^2/sec	0.632 – 0.330

Shankarananth and Jaivignesh (2016) presented a parametric experimental study of utilization of glass powder, GGBS, Perlite ore in fly ash brick manufacturing. Glass powder, Perlite ore is taken as constant of 2%, 10% and GGBS is replaced with 10%, 20% and 30% for each proportion that have been calculated. The physical and mechanical properties of fly ash brick are investigated. These bricks were tested for compressive strength, water absorption, efflorescence, density and soundness test after 21 days curing as per Indian Standards. The result showed greater compressive strength than the ordinary first class bricks and it also concludes better water absorption, 1300- 1500kg/m^3 density and good soundness by a clear ringing sound.

Xu et al. (2016) produced a new type of rubber and perlite mortar modified by SBR latex and polyester. Thermal and mechanical properties were studied. The experimental results showed that the amount of rubber and perlite have a major influence in a compressive strength and thermal conductivity. With increasing rubber and perlite dosages, the compressive strength and thermal conductivity decreases. The reduction in compressive strength was 25–65%, as compared to the control mortar. The reduction of thermal conductivity was 6–12% and 30–35% for rubber and perlite respectively.

Zulkifeli and Saman (2016) evaluated experimentally the effect of fire on the perlite cement mortar. The sand was replaced by perlite with the contents of 10%, 20%, 30%, and 40% by volume. The mortars were exposed to different high temperatures of 200°C, 400°C, 700°C, and 1000°C. The compressive strength was reduced with increasing the perlite content, particularly for low temperature exposure, while the performance improved in high temperature.

Arunraja, et al., (2017) investigated mechanical properties of light weight bricks using perlite and lime. This work effectively converts perlite into useful building materials like building bricks and floor interlocks which can effectively reduce the self weight or dead load and further decreases the problem of fire industries accidents in the society. Rather than the expanded perlite going into the landfill or incinerators it can be used as construction materials at a much lower cost after undergoing certain specific processing. This brick is floating in the water. The specimen size was 190mmX90mmX90mm. These bricks were made of perlite and lime in various ratios like 70:30, 75:25, 80:20 and 85:15. From the compression testing results found that expanded perlite material when effectively mixed lime gives the 3.3 N/mm^2 compressive strength.

Naveen et al., (2018), studied the effect of compositions of bagasse ash and perlite admixture on thermal stresses and other mechanical properties of clay were investigated. The samples were dried and then finally fired in the furnace at 800°C for a final curing. Their fired densities varied between 1790 and 1230 kg/m^3, which correspond to a decrease of 27%, when compared to the density of the brick without admixture. Apparent water absorption values were increased with increase in Bagasse ash, Perlite addition. Properties which include thermal shock resistance, cold crushing strength and porosity were obtained by the appropriate standard test methods. The microstructures and weight loss percentage (%) corresponding to temperature variation of the fired samples were characterized with SEM-EDS and TGA. The results show that the amount of bagasse ash and perlite admixture affects the properties variously; porosity and thermal resistance increases with percentage increase in bagasse ash and perlite, thermal and mechanical properties were also evaluated by ANSYS.

Satakhun et al., (2018), investigated on masonry and plastering mortars made from Portland cement, fly ash, expanded perlite, mortar plasticizer and sand. For the masonry mortar, the mixes with high calcium fly ash with or without plasticizer could be used with required properties and reduced cost. The mix of expanded perlite gave water retention over the required 70%. The mix containing fly ash and 0.2% plasticizer gave water retention slightly less than 70%. It was recommended that the mix with expanded perlite should be used for indoor plastering and the mix with fly ash and plasticizer should be used for outdoor plastering.

2.2.2 Energy savings in the production of bricks using perlite

Ilker and Burak (2006) investigated on different methods for achieving heat insulation in the buildings. Manufacturing of high heat conductivity resistant construction materials is an important part of these research efforts. High heat resistant brick can be produced by adding perlite into the clay in conventional brick manufacturing. In this investigation perlite of Eskisehir region and clay were collated and fired to form high heat conductivity resistant material. Binding materials such as cement, gypsum, lime, bitumen and clay were used for manufacturing perlite brick. Bricks in standard sizes manufactured at different perlite- clay ratios and unit weight, compressive strength, volume reduction and heat conductivity values were obtained. Compressive strength decreases, heat conductivity resistant and shrinkage of perlite bricks increase as the replacement ratio of perlite increases (Figure 2.9, Figure 2.10

and Figure 2.11). Results were examined according to combined properties, and specialties of perlite bricks were determined at various weights. As a result, the best mixture was determined as the one containing 30% perlite.

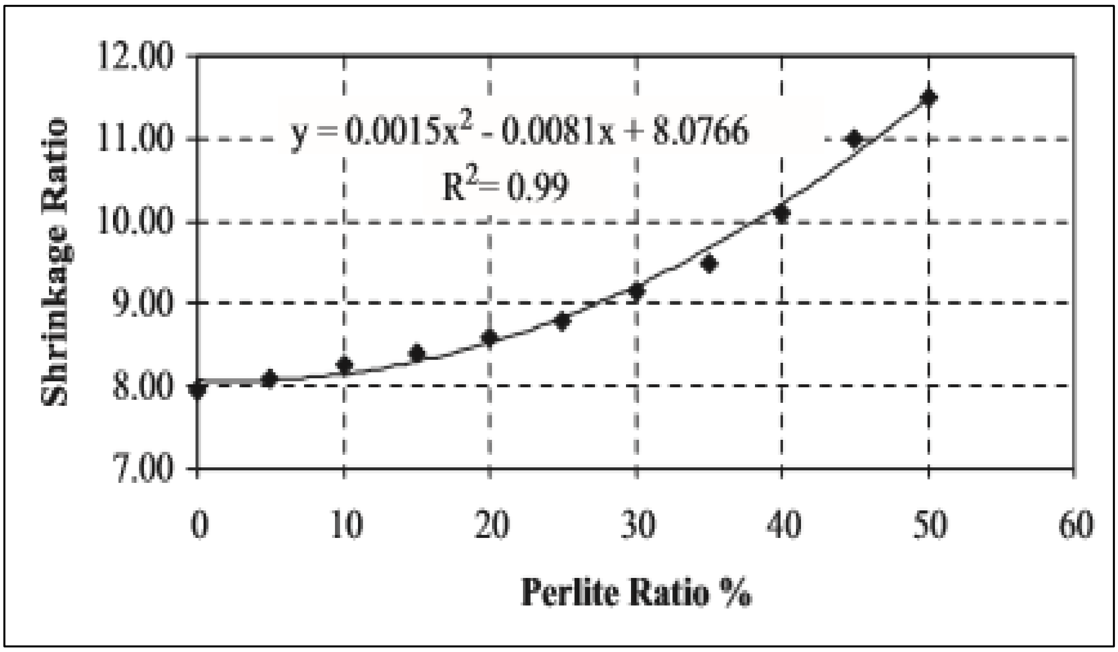

Figure 2.9 Shrinkage of perlite bricks according to perlite ratio (Ilker and Burak, 2006)

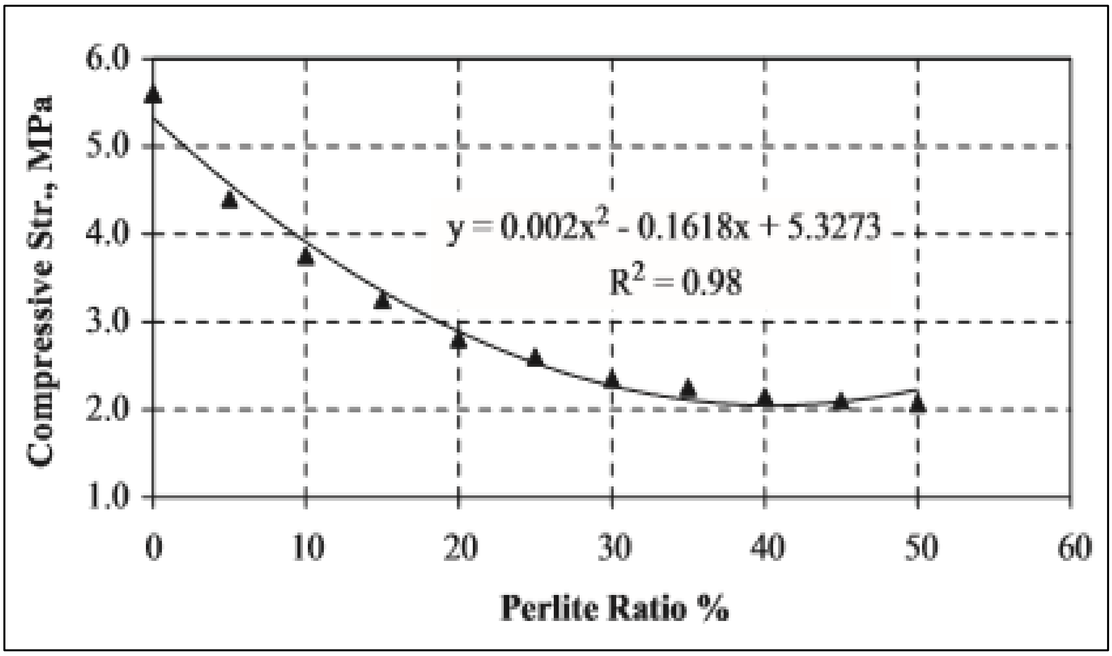

Figure 2.10 Compressive strength of perlite bricks according to perlite ratio (Ilker and Burak, 2006)

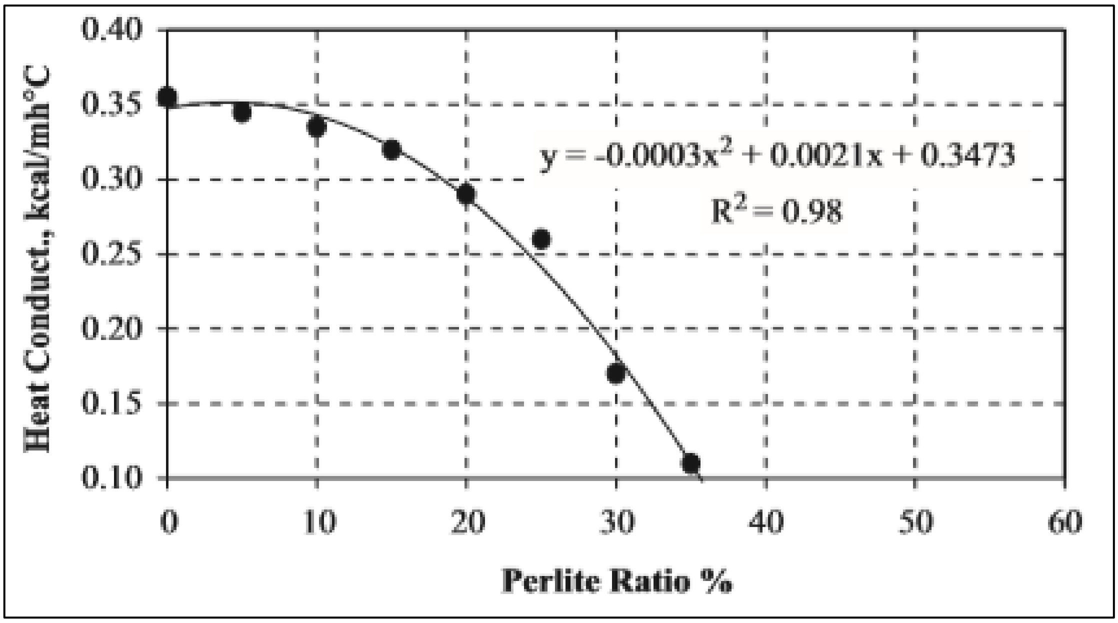

Figure 2.11 Heat conductivity of perlite bricks according to perlite ratio (Ilker and Burak, 2006)

Jedidi et al., (2015) carried out an experimental study in order to provide more data on the effects of expanded perlite aggregate (EPA) dosage on the compressive strength and thermo physical properties of lightweight concrete at different ages. The first part of this experimental study was devoted to the choice of the proper mixing procedure for expanded perlite concrete (EPC). Thereafter, six sets of cubic specimens and six sets of parallelepiped specimens were prepared at a water-to-cement ratio of 0.70 with varying replacement percentages of sand by EPA ranging from 0% to 80% by volume of sand. Compressive strength, thermal conductivity and thermal diffusivity were determined over curing age. Unit weights for the mixtures prepared varied between 560 and 1510 kg/m^3. Compressive strength was decreased when perlite content was increased. The test results indicated that replacing natural aggregate by EPA increased the thermal resistance of the lightweight concrete and consequently, improved thermal insulation.

Arici et al., (2016) investigated on heat insulation performance of hollow clay bricks filled with perlite. Heat transfer through various hollow bricks, which are widely used in Turkey, is analyzed numerically. Calculations are carried out for three scenarios for each type of hollow brick: (i) cavities are filled with air, (ii) half of the cavities are filled with perlite while the other half with air, (iii) all cavities are filled with perlite. The computed results shown that filling the cavities with perlite inhibits convection and radiation in cavities. Hence effective thermal conductivity thus heat loss (or heat gain) reduces significantly for all types of bricks.

The enhancement in heat insulation performance can be up to 15.6% and 27.5% for half perlite and full-perlite cases respectively depending on the brick type. It is concluded that since filling the cavities of hollow bricks with perlite, provides a high potential of reducing effective conductivity, it should be considered by engineers to build residential or office buildings with low energy consumption.

Georgiev et al., (2017) studied on effect of expanded vermiculite and expanded perlite as pore forming additives on the physical properties and thermal conductivity of porous clay bricks. It has been established the effect of the quantity of 0, 3, 5 and 8 mass % of two pore-forming additives as expanded vermiculite and expanded perlite on the properties of the fired at 900^{o}Cporous ceramic brick samples. The apparent density of the fired ceramic brick samples decreases with the increasing of pore forming amount due to the increased number of pores created by expanded vermiculite and expanded perlite during firing. By increasing the amount of pore-forming additive increases porosity and decreases the thermal conductivity of the samples. For contents of small amounts of pore-forming additive in the ceramic bodies, the changes of physical properties and thermal conductivity are less pronounced. Thermal conductivity of the porous brick sample with 8 mass % vermiculite produced at 900^{o}C compared to the brick without additive, decreases from 1.1 to 0.8 W/mK (Figure 2.12). Expanded vermiculite and expanded perlite in amounts of 8 mass % could be used as a pore forming agents in bricks production to improve thermal conductivity of clay bricks and keep acceptable compressive strength.

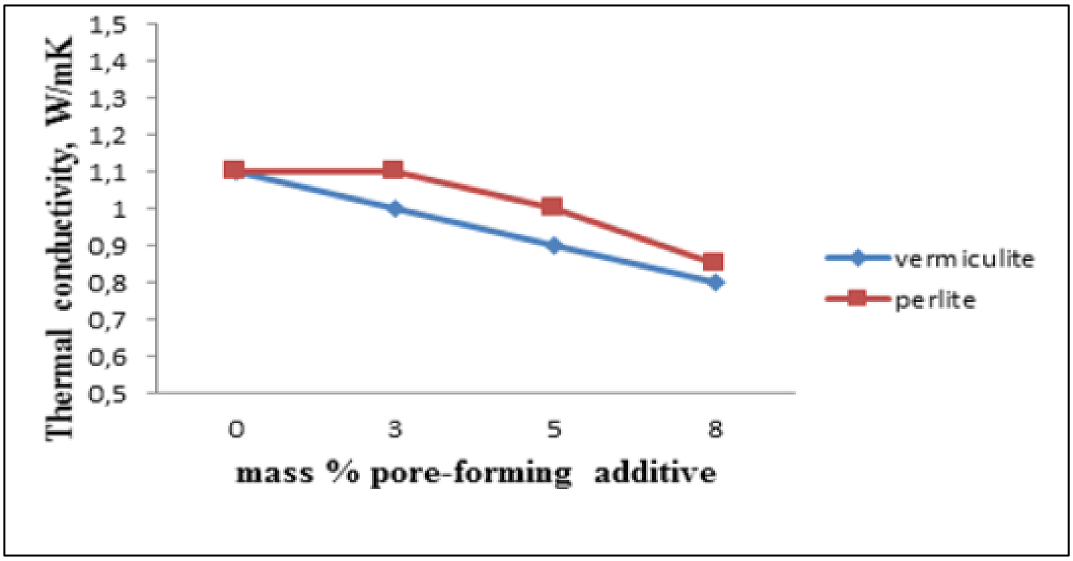

Figure 2.12 Thermal conductivity of ceramic porous samples fired at 900^{o}C (Georgiev et al., 2017)

Bullibabu & Ali., (2018) investigated on the reduction of thermal conductivity in clay-based construction materials. Clay is the basic material for brick production, bagasse and perlite were additive elements in clay, bagasse is a sugar industrial waste and perlite, which is from siliceous volcanic rock. Bagasse facilitates the porous nature in brick and perlite consists of rich amount of Al_2O_3 and SiO_2, while thermal insulation properties improve in clay based construction materials. The result shows that an increasing quantity of the bagasse and perlite in the clay mixture significantly decrease the thermal conductivity of clay brick, and a small reduction in compressive strength was observed.

Uluer et al., (2018) mathematically calculated and experimentally investigated on expanded perlite based heat insulation materials' thermal conductivity. Thermal resistance can be increased by using proper heat insulation materials. Traditional heat insulation materials do not stand all desired properties. Thus, developing new heat insulation materials is very important. In this study, expanded perlite based heat insulation material was developed as an alternative to the traditional insulation materials. The composition of the developed material was designed and prepared using the theoretical thermal conductivity prediction models. The prepared material was moulded in a rectangular shape panel. Thermal conductivity of panels was measured experimentally and the results were compared with the calculated results. Also, the results showed that the developed panels can be used for heat insulation applications. On the other hand, the closest model to the experimental results is the parallel model whose average deviation is 4.22% while the farthest model is the Cheng and Vachon model whose average deviation is 12.43%. It is observed that parallel and series models are generally in good agreement with the experimental results. Nevertheless, it is seen some deviations between experimental and theoretical calculation results. The theoretical prediction models do not include any processing conditions such as moulding and curing. It is thought that these deviations have originated because of the missing processing parameters in theoretical prediction models. As a result of experimental studies, the lowest thermal conductivity value of expanded perlite based panels was obtained as 43.5 mW/mK. Consequently, the heat transfer coefficient of the panels containing expanded perlite can be calculated nearly by the parallel method.

From the extensive survey of above literature, the review can be summarized as follows:

- The above literature review gives the road map of using IOT in bricks, autoclave blocks, concrete, pavements with an advantage of sustainability of environment, waste management simultaneously enhancing the properties of construction materials.

- Use of perlite has given a way to have light weight blocks and materials with the benefit of thermal conductivity and electrical resistivity sustaining the IS standard strength at a particular replacement percentage.

  Based on above review, it was found that no research is reported yet on utilization of IOT with perlite as an additive to make bricks., which is identified as major research gap.

  So, the Research started after the study of detailed literature on improvements of properties of bricks and decided to work on environmental friendly energy efficient bricks using IOT and Perlite.

- Based on the review of literature, it was decided to make an attempt to examine the economic analysis of brick (IOT - Perlite brick) covering different aspects such as material, financial, production, labour, energy and environment. This is a unique study which includes thermal conductivity, which are not so far covered, to make a little contribution in the development of brick industry.

CHAPTER-3

CHAPTER – 3

EXPERIMENTAL INVESTIGATIONS

This chapter gives the details of laboratory investigations and pilot scale studies, like:

- Collection of required samples.
- Determination of physico chemical properties and sieve analysis in laboratory
- Casting of bricks with different composition
- Curing the moulded bricks for required duration
- Determination of various properties of finished bricks like unconfined compressive strength (UCS), durability, density, water absorption, thermal conductivity, etc.
- Pilot scale study to assess the thermal efficiency of IOT- perlite bricks in comparison with conventional bricks

3.1 Collection of Samples

The materials used in the research work are Iron Ore Tailings (IOT), Perlite, Sand and Cement.

3.1.1 Iron ore tailings

IOT samples are collected from tailings dam of a Mining Company in Bellary district of Karnataka State using random sampling method (Figure 3.1) and safety precautions were taken by wearing protective gloves and mask. IOTs are the by-product produced in the beneficiation process of iron ore under certain technologies. Around three tonnes of IOT collected and transported to the laboratory where the research work is being carried out. The mine management was kind enough to give the material at free of cost.

3.1.2 Sand

Locally available river sand is used for present investigations as fine aggregates confirming to IS 2116: 1980 were used.

Figure 3.1 Collecting iron ore tailings from a tailings pond

3.1.3 Cement

Ordinary Portland Cement (OPC) of Grade 53 (ACC) available in local market confirming to IS 12269:2013 is used in casting bricks. The cement is of uniform colour i.e. Grey with a light greenish shade and was free from any hard lumps.

3.1.4 Perlite

Perlite is procured from M/S. Keltech Energies Limited (KEL), Vishwasnagar, Udupi District of Karnataka. The particles of perlite are chemically inert, very light weight, mildly abrasive and inorganic material with a porous structure. The quantity of perlite used for preparing bricks is 54kg (i.e. 9bags containing 6kg in each bag). Cost of perlite per kg is Rs. 30, therefore total cost of perlite used in preparing bricks are Rs. 1620.

3.2 Physical and Chemical Properties of Samples

3.2.1 Iron ore tailings

Sieve analysis of IOT is carried out and the results are given in Table 3.1. A typical Particle–size distribution curve of the tailings is shown in Figure 3.2. The particles ranging from 4.75 mm and below are used as fine aggregates in making the tailings bricks. It is brick red in colour and has specific gravity of 2.71 and water absorption is

2.29%. Chemical compositions of tailings are presented in Tables 3.2 and the elements present in IOT are given in Table 3.3.

Table 3.1 Particle size distribution of iron ore tailings

Sieve Size	Weight (Wt.), %
Above 1.18 mm	21.40
600µ to 1.18mm	50.20
300µ to 600µ	13.20
15µ to 300µ	6.60
Below 15µ	8.60
Average	**100.00**

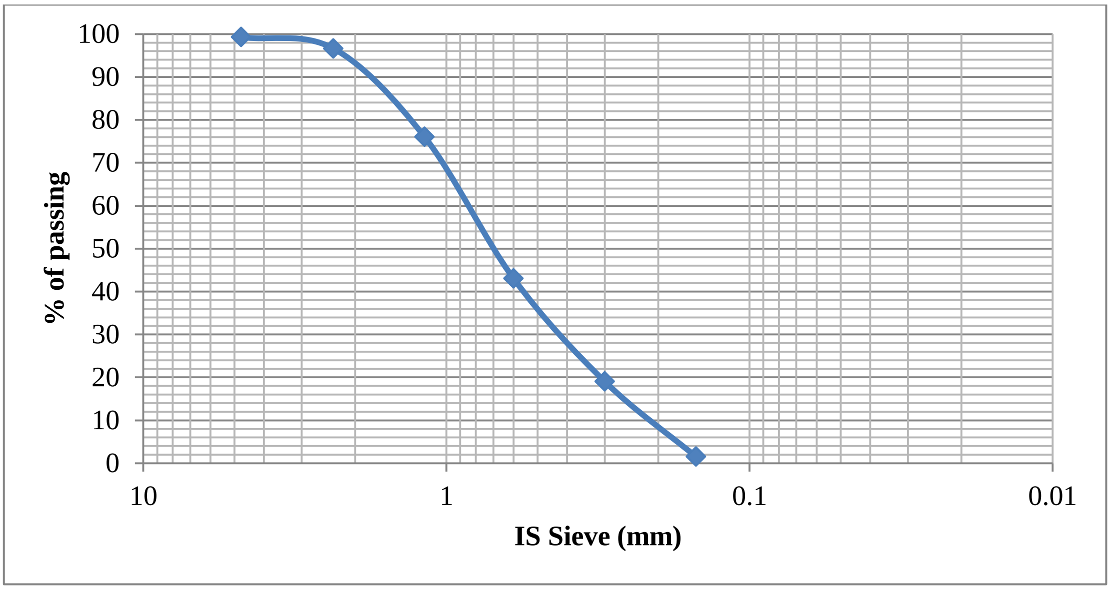

Figure 3.2 Particle size distribution of iron ore tailings

Table 3.2 Chemical composition of iron ore tailings

Chemical Component in IOT	SiO_2	Al_2O_3	Fe_2O_3	CaO	MnO	K_2O	ZnO	CuO	PbO	LOI
% of component	56	10	8.3	4.3	1.7	1.5	0.1	0.2	0.4	3.3

Table 3.3 Percentage of elements present in iron ore tailings

Element	Weight, %	Atomic Weight, %	Error, %
O	34.36	59.41	7.33
Al	9.01	9.24	8.58
Si	7.36	7.25	8.20
Pb	1.24	0.17	16.21
K	0.23	0.16	66.49
Ca	0.41	0.28	52.65
Mn	0.91	0.46	33.40
Fe	46.48	23.03	2.78

3.2.2 Sand

Natural river sand is used for the studies. The water absorption and specific gravity of the sand are 0.1% and 2.65 respectively. Figure 3.3 shows the grain size distribution curve of sand. The maximum and minimum dry density is determined by using relative density equipment and found to be 1870kg/m^3 and 1500kg/m^3 respectively.

The uniformity coefficient (Cu) which is defined as a ratio and is calculated as the size opening that will just pass 60% of the sand (D_{60} value) divided by the size opening that will just pass 10% of the sand sample (D_{10} value). Coefficient of Curvature is the parameter estimated using the gradation curve through sieve analysis. This parameter is used to classify the soil as well graded or poorly graded and is given by the relation as shown in equation 3.1.

$$Cc = D^2_{30} / (D_{10} \times D_{60})$$ ……………… **Equation 3.1**

The uniformity coefficient (Cu) and coefficient of curvature (Cc) are found for the collected sand sample is 3.57 and 1.70 respectively. The value of Cu and Cc shows that the sand is well graded.

The D_{50} is the size in microns that splits the distribution with half above and half below this diameter or the portion of particles with diameters smaller and larger than this value are 50%, and also known as the median diameter. The median diameter (D_{50})of sand used in manufacturing of brick is 0.89.

From sieve analysis, it is noticed that collected river sand percentage passing lies between the given percentage of passing in Zone I of sand grading chart. Therefore, Zone I sand passing through 4.75 mm sieve is used for casting of bricks (Table 3.4). The elements present in sand are given in Table 3.5.

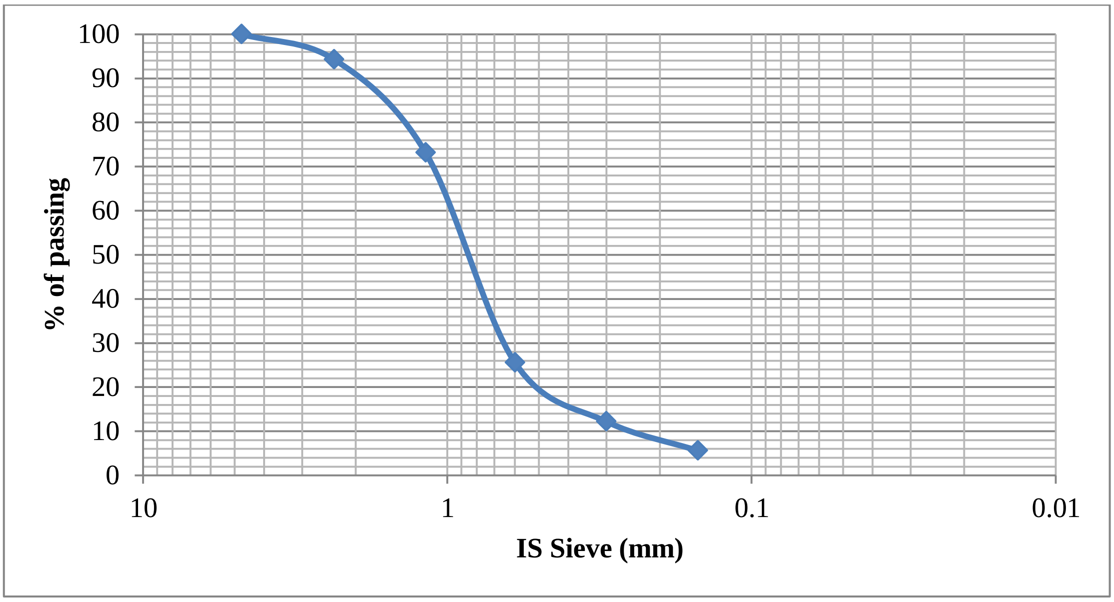

Figure 3.3 Grain size distribution of sand

Table 3.4 Sieve analysis and grading of sand

IS Sieve	Percentage of passing of collected river sand	Percentage passing for Grading Zone I
10mm	100	100
4.75mm	100	90 – 100
2.36mm	94.3	60 – 95
1.18mm	73.2	30 – 70
600 micron	25.6	15 – 34
300 micron	12.2	5 – 20
150 micron	5.6	0 – 10

Table 3.5 Percentage of elements present in sand

Element	Weight, %	Atomic Weight, %	Error, %
O	43.29	58.16	8.87
Na	0.67	0.62	35.14
Mg	0.88	0.78	16.13
Al	4.82	3.84	7.05
Si	44.46	34.03	4.01
K	0.66	0.36	32.43
Ca	1.26	0.68	19.91
Fe	3.96	1.53	11.61

3.2.3 Cement

Portland cement is used for research studies. Ordinary Portland Cement (OPC) of grade53 conforming to IS 12269:1987 was used. It is grey in color; particle size ranges from 0.007 to 0.2mm and has a specific gravity of 3.15. The chemical composition and physical properties of cement are taken from manufacturer and the details are given in Table 3.6 and Table 3.7 respectively (www.acchelp.in).

Table 3.6 Chemical composition of ordinary portland cement

Sl. No.	Chemical Composition	Results	Requirements as per IS: 12269: 1987
1.	Soluble Silica, %	21.4	----------
2.	Alumina, %	5.1	----------
3.	Iron Oxide, %	3.6	----------
4.	Lime, %	63.8	----------
5.	Magnesia, %	0.8	Not more than 6.0%
6.	Insoluble Residue, %	0.8	Not more than 3.0%
7	Sulphur calculated as SO_3, %	2.3	Not more than 2.5 if C_3A is 5.0 or less & not more than 3.0 if C_3A is more than 5.0%
8.	Loss on Ignition, %	1.6	Not more than 4.0%
9.	Lime Saturation factor	0.91	Between 0.80 & 1.02
10	Proportion of Alumina to Iron Oxide	1.42	Not less than 0.66
11	Tri Calcium Aluminate	7.42	----------
12	Chloride, %	0.022	Not more than 0.1%

Table 3.7 Physical properties of ordinary portland cement

Sl. No.	Physical Properties	Results	Requirements as per IS: 12269: 1987
1.	Fineness: Specific Surface, m^2/kg	 349	 Not less than 225
2.	Compressive Strength, MPa: at 3 Days 7 Days 28 Days	 42.0 52.0 65.0	 Not less than 27 Not less than 37 Not less than 53
3.	Setting Time, minutes Initial Final	 195 280	 Not less than 30 Not more than 600
4.	Soundness: Le-Chatelier Expn., mm Autoclave Expn., %	 1.0 0.06	 Not more than 10mm Not more than 0.8%
5.	Normal Consistency, %	28.0	----------

3.2.4 Perlite

Perlite is procured from Keltech Energies Ltd and its properties are provided by the manufacturer (www.keltechenergies.com). The chemical composition of perlite is given in Table 3.8. Physical properties of Perlite are given in Table 3.9. The elements present in perlite are given in Table 3.10.

Table 3.8 Typical chemical composition of perlite

Chemical composition		%
Silicon dioxide	SiO_2	71-75
Alumina	Al_2O_3	12.5-18
Iron oxide	Fe_2O_3	0.5-1.5
Magnesium oxide	MgO	0.5-1.5
Quick lime	CaO	0.5-2.0
Caustic soda	Na_2O	2.9-4
Potassium oxide	K_2O	4-5
Hardness on Mohr’s scale		3-4

Table 3.9 Typical physical properties of perlite

S. No	Property	Value
1	Colour	Whitish grey
2	Apparent density, kg/m^3	150
3	Specific Gravity	2.3
4	pH	6.5
5	Water absorption, % of mass	250
6	Thermal conductivity, W/mK	0.043

Table 3.10 Percentage of elements present in perlite

Element	Weight, %	Atomic Weight, %	Error, %
O	48.39	62.56	8.65
Na	3.76	3.38	11.61
Mg	0.79	0.67	15.60
Al	7.56	5.79	5.95
Si	33.19	24.44	4.44
K	4.22	2.23	7.70
Ca	0.78	0.40	25.80
Ti	0.55	0.24	34.00
Fe	0.76	0.28	38.29

3.3 Mix Proportion

The materials for manufacturing the brick consists of iron ore tailings, sand, cement and perlite. To make the IOTs – Perlite brick following mix proportion are arrived by trial and error method. The Table 3.11 shows the various mix proportions. The mixture contains perlite as additives, whereas added in percentage of 0, 2 and 5. Initially, casting of bricks is considered without any perlite. Cement percentage is fixed at 10%, and from remaining 90%, sand is replaced with IOT, 30 to 60%, with 10% incremental order. Similarly, in the next stage, cement percentage is increased to 15% and later 20%, and the same process is followed. Later perlite is increased to 2% & 5% and the same process is followed as shown in the Table 3.11.

Table 3.11 Various mix proportions for bricks

Proportion	Iron Ore Tailings, %	Sand, %	Cement, %	Perlite, %
1	30	60	10	0
2	40	50		
3	50	40		
4	60	30		
5	30	58	10	2
6	40	48		
7	50	38	10	2
8	60	28		
9	30	55	10	5
10	40	45		
11	50	35		
12	60	25		
13	30	55	15	0
14	40	45		
15	50	35		
16	60	25		
17	30	53	15	2
18	40	43		
19	50	33		
20	60	23		
21	30	50	15	5
22	40	40		
23	50	30		
24	60	20		
25	30	50	20	0
26	40	40		
27	50	30		
28	60	20		
29	30	48	20	2
30	40	38		

Proportion	Iron Ore Tailings, %	Sand, %	Cement, %	Perlite, %
31	50	28		
32	60	18		
33	30	45	20	5
34	40	35		
35	50	25		
36	60	15		
37	50	23	20	7

Volume of one brick is 0.00199m^3. The weight of each raw material is calculated by multiplying its percentage in the brick to its density which is given in Table 3.12. The quantity of each raw materials are calculated as :

Quantity of material = Volume of the brick X percentage of the raw material X density ………..**Equation 3.2**

Table 3.12 Quantity of materials used in each brick

Proportions	Iron Ore Tailings, kg	Sand, kg	Cement, kg	Perlite, kg
1	1.07	2.089	0.318	0
2	1.43	1.741	0.318	0
3	1.79	1.393	0.318	0
4	2.15	1.045	0.318	0
5	1.07	2.020	0.318	0.006
6	1.43	1.672	0.318	0.006
7	1.79	1.323	0.318	0.006
8	2.15	0.975	0.318	0.006
9	1.07	1.915	0.318	0.015
10	1.43	1.567	0.318	0.015
11	1.79	1.219	0.318	0.015
12	2.15	0.871	0.318	0.015
13	1.07	1.915	0.477	0
14	1.43	1.567	0.477	0
15	1.79	1.219	0.477	0

Proportions	Iron Ore Tailings, kg	Sand, kg	Cement, kg	Perlite, kg
16	2.15	0.871	0.477	0
17	1.07	1.846	0.477	0.006
18	1.43	1.497	0.477	0.006
19	1.79	1.149	0.477	0.006
20	2.15	0.801	0.477	0.006
21	1.07	1.741	0.477	0.015
22	1.43	1.393	0.477	0.015
23	1.79	1.045	0.477	0.015
24	2.15	0.696	0.477	0.015
25	1.07	1.741	0.637	0
26	1.43	1.393	0.637	0
27	1.79	1.045	0.637	0
28	2.15	0.696	0.637	0
29	1.07	1.672	0.637	0.006
30	1.43	1.323	0.637	0.006
31	1.79	0.975	0.637	0.006
32	2.15	0.627	0.637	0.006
33	1.07	1.567	0.637	0.015
34	1.43	1.219	0.637	0.015
35	1.79	0.871	0.637	0.015
36	2.15	0.522	0.637	0.015
37	1.79	0.801	0.637	0.021

3.4 Preparation of Bricks

Thorough mixing of the materials is essential for the production of uniform product. The mixing should ensure that the mass becomes homogeneous, uniform in colour and consistency. Normally, a batch mix made with ingredients corresponding to different percentage of IOTs, sand, perlite and cement.

The normal hand mould is used to cast the bricks in the laboratory with the standard size of 23.0 cm length, 11.25 cm width and 7.5 cm height (Figure 3.4). They are casted according to the standard procedure with various mix proportions arrived. The required quantity of IOTs, Sand, Cement and Perlite is calculated previously; accordingly, the materials are mixed.

Then the required quantity of water is added and mixed thoroughly. The prepared mix is poured into the mould and it is compacted. After casting, all the test specimens are kept at room temperature for 24 hours and then demoulded. These are then placed in water curing tank.

Curing is one of the most essential part of brick production. Optimum curing duration has a major effect on the quality of the end product. The curing of brick is most important as it is very essential for keeping the hydration process of cement until brick attains the maximum compressive strength, which increases but slowly after 21days from initial placing time. Hence the bricks are cured for 21 days in water tank. Bricks are casted in 6 numbers for each varying proportion of IOT, cement, sand, perlite and water combination (Table 3.13).

Accordingly for 10 and 15 percentage of cement, 336 samples are casted and whereas for 20% cement, 364 samples are casted. In total 1036 samples are casted. Infact more than 1500 samples are casted and some of them are wasted during different tests. For pilot scale study further 1000 bricks are casted.

Mixing

Moulding

Figure 3.4 A view of casting of bricks

Table 3.13 Samples casted for various experiments by retaining 10% cement as constant

Name of the test	**Curing period in days**	**Number of samples casted with 10% cement content**											
		A-30% B-60% C-0%	A-40% B-50% C-0%	A-50% B-40% C-0%	A-60% B-30% C-0%	A-30% B-58% C-2%	A-40% B-48% C-2%	A-50% B-38% C-2%	A-60% B-28% C-2%	A-30% B-55% C-5%	A-40% B-45% C-5%	A-50% B-35% C-5%	A-60% B-25% C-5%
Water absorption	21	6	6	6	6	6	6	6	6	6	6	6	6
Compressive strength	21	6	6	6	6	6	6	6	6	6	6	6	6
Thermal conductivity	21	16	16	16	16	16	16	16	16	16	16	16	16
Sub Total		**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**
Total		**336**											

Notation: A- IOT, B- sand, C- Perlite

Bricks with 0%, 2% and 5% of perlite and 15% of cement as constant for various proportions of IOT and sand are casted. These bricks are tested for water absorption, compressive strength and thermal conductivity. Details of number of samples casted in each case for 15% of cement are given in Table 3.14.

Table 3.14 Samples casted for various experiments by retaining 15% cement as constant

Name of the test	**Curing period in days**	**Number of samples casted with 15% cement content**											
		A-30% B-55% C-0%	A-40% B-45% C-0%	A-50% B-35% C-0%	A-60% B-25% C-0%	A-30% B-53% C-2%	A-40% B-43% C-2%	A-50% B-33% C-2%	A-60% B-23% C-2%	A-30% B-50% C-5%	A-40% B-40% C-5%	A-50% B-30% C-5%	A-60% B-20% C-5%
Water absorption	21	6	6	6	6	6	6	6	6	6	6	6	6
Compressive strength	21	6	6	6	6	6	6	6	6	6	6	6	6
Thermal conductivity	21	16	16	16	16	16	16	16	16	16	16	16	16
Sub Total		**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**
Total		**336**											

Notation: A- IOT, B- sand, C- Perlite

Bricks with 20% cement content and with 0%, 2% and 5% perlite were casted (Table 3.15). Water absorption, compressive strength and thermal conductivity were tested.

Table 3.15 Samples casted for various experiments by retaining 20% cement as constant

Name of the test	Curing period in days	Number of samples casted with 20% cement content												
		A-30% B-50% C-0%	A-40% B-40% C-0%	A-50% B-30% C-0%	A-60% B-20% C-0%	A-30% B-48% C-2%	A-40% B-38% C-2%	A-50% B-28% C-2%	A-60% B-18% C-2%	A-30% B-45% C-5%	A-40% B-35% C-5%	A-50% B-25% C-5%	A-60% B-15% C-5%	A-50% B-23% C-7%
Water absorption	21	6	6	6	6	6	6	6	6	6	6	6	6	6
Compressive strength	21	6	6	6	6	6	6	6	6	6	6	6	6	6
Thermal conductivity	21	16	16	16	16	16	16	16	16	16	16	16	16	16
Sub Total		**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**	**28**
Total	**364**													
Grand Total	**336 + 336+ 364 = 1036**													

Notation: A- IOT, B- sand, C- Perlite

3.5. Laboratory Investigations

Quality assessment and durability tests are carried out to obtain optimum percentage of raw materials. After curing, the bricks are subjected to quality assessment tests like unconfined compressive strength (UCS); durability tests such as water absorption and thermal conductivity. Density of brick is determined to check its weight and degree of compactness of material and efflorescence test is done to ascertain its suitability to retain the aesthetic appearance of the building.

Brick production is designed for different proportions. Iron ore tailings (IOT) were varied for percentage of 30, 40, 50 and 60 by keeping cement as constant 10%, 15% and 20% and perlite as 0%, 2% and 5% for all proportions of IOT.

3.5.1 Density

Density is also called as unit weight of substance. Density represents the degree of compactness of material. If the material is of higher density, it is more compacted material. Density of construction materials are its mass per unit volume. Its value of construction material will also help to find out the quantity of material needed for particular space. It also helps to know the dead load acting on the building. It is expressed in kg/m^3 and shows compactness of building material.

Weight and density of bricks of size 230 x 112.5 x 75 mm are determined. The brick placed on the dry cloth and gently surface dried with the cloth, and transferred it to the second dry cloth, if the first cannot remove moisture further. Then it is exposed to the atmosphere away from direct sunlight or any other source of heat for not less than 10 minutes or until it appears to be completely surface dry and then weight of individual brick is recorded as per IS 1077:1963. On the basis of weight and volume, density of bricks is calculated and only average dry density calculated is given in Table 3.16. The detail readings of density of 6 bricks casted for each different proportion of raw materials are given in Appendix A (Table A- 1).

Table 3.16 Density of bricks for different percentage of raw materials

Sl. No	Percentage of Raw materials, %				Average Dry Weight, kg	Average Density, kg/m^3
	IOTs	Sand	Perlite	Cement		
1.	30	60	0	10	3.404	1754.32
2.	40	50			3.472	1789.11
3.	50	40			3.577	1843.29
4.	60	30			3.685	1898.87
5.	30	58	2	10	3.331	1716.45
6.	40	48			3.360	1731.60
7.	50	38			3.412	1758.22
8.	60	28			3.462	1783.96
9.	30	55	5	10	2.399	1236.19
10.	40	45			2.401	1237.23
11.	50	35			2.412	1242.89
12.	60	25			2.492	1284.12
13.	30	55	0	15	3.461	1783.44
14.	40	45			3.479	1792.72
15.	50	35			3.582	1845.79
16.	60	25			3.691	1901.96
17.	30	53	2	15	3.378	1740.67
18.	40	43			3.395	1749.45
19.	50	33			3.412	1759.32
20.	60	23			3.482	1794.27
21.	30	50	5	15	2.499	1287.73
22.	40	40			2.504	1290.30
23.	50	30			2.544	1310.92
24.	60	20			2.595	1337.19
25.	30	50	0	20	3.520	1813.85
26.	40	40			3.582	1845.79
27.	50	30			3.635	1873.12
28.	60	20			3.692	1902.48

Sl. No	Percentage of Raw materials, %				Average Dry Weight, kg	Average Density, kg/m³
	IOTs	Sand	Perlite	Cement		
29.	30	48	2	20	3.420	1762.31
30.	40	38			3.452	1778.81
31.	50	28			3.485	1795.81
32.	60	18			3.597	1853.53
33.	30	45	5	20	3.080	1587.36
34.	40	35			3.257	1678.32
35.	50	25			3.362	1723.43
36.	60	15			3.412	1758.19
37	50	23	7	20	2.142	1103.76

3.5.2 Water absorption

The bricks are weighed after immersing in water for 24 hours and later placed in oven till it reaches a stage of constant weight and based on initial and final weight, water content is determined. The water absorption test is performed according to IS 3495(part II): 1992. The percentage of water absorption (w_a) is calculated using following formula.

$$w_a = \frac{w_2 - w_1}{w_1} \times 100$$ ---------------- **Equation 3.3**

Where, w_1 is the weight of the dry brick after keeping in oven for 24 hours at 100°C temperature; and w_2 is the weight of the brick after curing at the specified temperature.

Water absorption test on bricks are conducted to determine durability property of bricks such as degree of burning, quality and behaviour of bricks in weathering. A brick with water absorption of less than 7% provides better resistance to damage by freezing. The degree of compactness of bricks can be obtained by water absorption test, as water is absorbed by pores in bricks. Water absorption test is conducted as per IS 3495:1992 Part II, which gives the percentage of water absorbed by bricks in 24 hours. Dry weights of six brick specimens of different percentage of IOT, sand, perlite and cement brick specimens are taken. All the specimens are immersed in water at the same time. The wet weight of specimens is recorded and the average percentage of water absorption is calculated for each different composition of specimen (Table 3.17). The water absorption reading of each bricks is given in Appendix – A (Table A – 2).

Table 3.17 Water absorption test results of bricks

Sl. No	Percentage of Raw Materials, %				Avg. Weight of Dry brick (M_1), kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOTs	Sand	Perlite	Cement			
1.	30	60	0	10	3.532	4.167	17.99
2.	40	50			3.567	4.220	18.30
3.	50	40			3.641	4.329	18.91
4.	60	30			3.522	4.274	21.30
5.	30	58	2	10	3.675	4.404	19.85
6.	40	48			3.686	4.428	20.14
7.	50	38			3.697	4.464	20.76
8.	60	28			3.725	4.579	22.92
9.	30	55	5	10	3.701	4.503	21.66
10.	40	45			3.710	4.538	22.32
11.	50	35			3.374	4.139	22.67
12.	60	25			3.389	4.203	24.01
13.	30	55	0	15	3.387	3.958	16.85
14.	40	45			3.624	4.258	17.50
15.	50	35			3.642	4.288	17.75
16.	60	25			3.765	4.446	18.08
17.	30	53	2	15	3.716	4.421	18.96
18.	40	43			3.722	4.451	19.58
19.	50	33			3.742	4.502	20.32
20.	60	23			3.374	4.139	22.67
21.	30	50	5	15	3.155	3.817	21.00

Sl. No	Percentage of Raw Materials, %				Avg. Weight of Dry brick (M_1), kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOTs	Sand	Perlite	Cement			
22.	40	40			3.167	3.862	21.96
23.	50	30			3.183	3.888	22.16
24.	60	20			3.242	3.984	22.90
25.	30	50	0	20	3.382	3.680	8.09
26.	40	40			3.350	3.627	8.29
27.	50	30			3.339	3.644	9.12
28.	60	20			3.335	3.654	9.56
29.	30	48	2	20	3.051	3.454	13.21
30.	40	38			2.776	3.152	13.53
31.	50	28			2.774	3.164	14.06
32.	60	18			1.908	2.187	14.61
33.	30	45	5	20	2.668	3.048	14.25
34.	40	35			2.740	3.137	14.50
35.	50	25			2.906	3.336	14.82
36.	60	15			3.276	3.788	15.64
37	50	23	7	20	3.270	3.780	15.60

3.5.3 Compressive Strength

The Uni-axial Compressive Strength (UCS) is tested using a compression testing machine as per IS 3495 (part I):1992 (Figure 3.5). Six bricks are tested in each case for the UCS and the average of the UCS values is taken for analysis purpose. Ultimate load at which the specimens failed is noted down to find the compressive strength. Rupture surface of the specimens after failure are visually inspected. Figure 3.5 shows a view of a specimen after failure in compression. The uni-axial compressive strength of the brick is calculated using following formula.

$$UCS = \frac{\text{Load (P)}}{\text{Cross –sectional area (A) of the brick}} \quad \text{.....................}\textbf{Equation 3.4}$$

Figure 3.5 Illustration of compression test on IOT – Perlite brick

Compressive strength test on bricks are carried out to determine the load carrying capacity of bricks under compression with the help of compression testing machine. Bricks are generally used for construction of load bearing masonry walls, columns and footings. These load bearing masonry structures experiences mostly the compressive loads. Thus, it is important to know the compressive strength of bricks to check for its suitability for construction. Cubic specimens are tested in compression testing machine after specified curing period in accordance with the IS specifications. The test results are given in Table 3.18 and the remaining readings of each brick tested for compressive strength is given in Appendix-A (Table A – 3).

Table 3.18 Compressive strength of different composition of bricks

Sl. No	**Percentage of Raw materials, %**				**Avg. Compressive Strength, MPa**
	IOTs	**Sand**	**Perlite**	**Cement**	
1.	30	60	0	10	3.56
2.	40	50			3.93
3.	50	40			4.12

Sl. No	Percentage of Raw materials, %				Avg. Compressive Strength, MPa
	IOTs	Sand	Perlite	Cement	
4.	60	30			4.76
5.	30	58	2	10	2.62
6.	40	48			2.69
7.	50	38			2.75
8.	60	28			2.83
9.	30	55	5	10	1.34
10.	40	45			1.41
11.	50	35			1.54
12.	60	25			1.67
13.	30	55	0	15	5.29
14.	40	45			6.10
15.	50	35			6.95
16.	60	25			7.10
17.	30	53	2	15	3.18
18.	40	43			3.28
19.	50	33			3.30
20.	60	23			3.56
21.	30	50	5	15	1.93
22.	40	40			1.93
23.	50	30			2.06
24.	60	20			2.41
25.	30	50	0	20	8.16
26.	40	40			9.62
27.	50	30			10.45
28.	60	20			11.19
29.	30	48	2	20	4.30
30.	40	38			4.45
31.	50	28			4.58
32.	60	18			4.72

Sl. No	Percentage of Raw materials, %				Avg. Compressive Strength, MPa
	IOTs	Sand	Perlite	Cement	
33.	30	45	5	20	3.68
34.	40	35			3.79
35.	50	25			3.89
36.	60	15			4.08
37.	50	23	7	20	1.79

3.5.4 Efflorescence

Efflorescence is a crystalline, salty deposit that occurs on the surfaces of bricks. It is white, sometimes a brilliant white or an off white colour. Efflorescence has been a real bug bear of the building and construction industry for many years. The formation of these salt deposits are not an inexplicable phenomena, they are simply water soluble salts that come from different sources to ruin the looks of the building. Presence of efflorescence causes disagreeable appearance, damp patches on wall and will even detach small fragments of the materials composing the wall. The liability of efflorescence shall be reported as nil, slight, moderate, heavy or serious in accordance as per IS 3495 (Part 3): 1992.

3.5.5 Thermal conductivity

The property that characterizes the ability of a material to transfer heat is thermal conductivity (k). It is a specific property of the material (k), which is a measure of the rate at which heat (energy) passes perpendicularly through a unit area of a homogenous material of unit thickness for a temperature difference of one degree Celsius. Thermal conductivity measurement is important to understand the heat flow in bricks. There are two main methods to measure thermal conductivity of materials, viz. the steady state method and the transient method (Bindiganavile & Suresh, 2012). Steady state methods are adopted for homogenous materials. In this method, the flux is proportional to the temperature gradient along the direction of flow. The experimental procedures are time consuming. However, the thermal conductivity values obtained by this method are accurate. The method of steady state thermal conductivity analysis includes, guarded hot plate method. The thermal conductivity test is performed according to the American Society for Testing & Materials (ASTM) C-177 and IS-3346.

The essential parts of Guarded Hot Plates are; the hot plates, the cold plates, the heater assembly, thermocouples and the specimens in position.

One dimensional heat flow through a flat specimen, an arrangement for maintaining its faces at constant temperature and a measure of heat flow through a known area for the measurement of thermal conductivity (k) is required. To eliminate the distortion caused by edge losses in unidirectional heat flow, the central plate is surrounded by a guard ring, which is separately heated. Temperatures are measured by calibrated thermocouples either attached to the plates or to the specimen at the hot and cold faces. Figure 3.6 shows the overall layout of a typical high-temperature guarded hot plate apparatus.

Knowing the heat input to the central plate heater, the temperature difference across the specimen, its thickness and the area, of the specimen, k can be calculated by using the following formula:

$$k = \frac{Q}{2A} \times \frac{L}{T_h - T_c} \quad \text{Watt/m}^{o}\text{C} \qquad \ldots\ldots\ldots\ldots \textbf{Equation 3.5}$$

Where, k = Thermal Conductivity of sample, W/m^{o}C or W/mk

Q = Heat flow rate in the specimen, Watts

A = Metering area of the specimen, m^2

T_h = Hot plate temperature, ^{o}C

T_c = Cold plate temperature, ^{o}C

L = Thickness of specimen, m

If the specimen thicknesses are different and the respective hot and cold temperature are different, then,

$$k = Q \times \left\{ \frac{1}{\frac{T_{h1} - T_{c1}}{L_1}} \times \frac{1}{\frac{T_{h2} - T_{c2}}{L_2}} \right\} \quad \text{W/mK (In S.I. units)} \ldots\ldots \textbf{Equation 3.6}$$

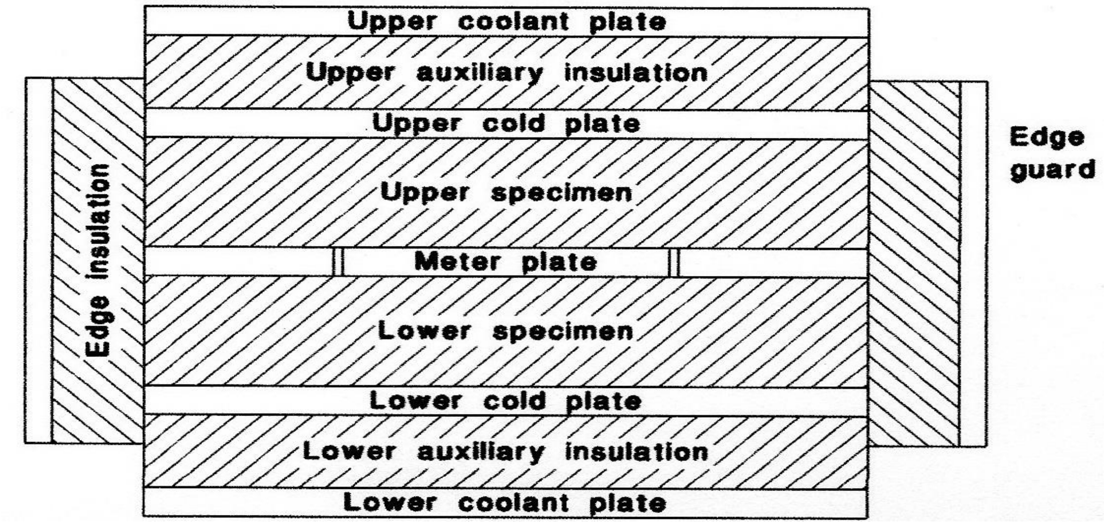

Figure 3.6 A typical high – temperature guarded hot plate apparatus (cross-section view)

Thermal conductivity test is conducted by placing the specimen on either side of the heating plate assembly, uniformly touching the cooling plates (Figure 3.7). Then the outer container is filled with loose fill insulation such as glass wool (supplied in small cloth packets). The cooling circuit is started, known input is given to central and guard heaters through separate single phase supply lines with a dimmer stat in each line and it is adjusted to maintain the desired temperature. The guard heater input is adjusted in such a way that there is no radial heat flow, which is checked from thermocouple readings and is adjusted accordingly. Power input to the central heater and the thermocouple readings is recorded after every 10 minutes till a reasonably steady state condition is reached. The final steady state values are taken for calculations.

Figure 3.7 A view of thermal conductivity apparatus

A pilot scale study is important to ensure the quality and efficiency of the laboratory study. This review discusses with a focus on the feasibility study on iron ore tailing and perlite in bricks. It also determines physical and chemical properties of IOT and perlite and how its reaction process affects in the bricks.

Raw materials are tested in laboratory to ensure that the raw materials used in brick products are suitable for their intended use. Conducting analysis on raw materials analysis using appropriate test methods and successfully meeting the challenges of such testing can prevent costly production problems and delays by confirming early in the production process. The laboratory testing of raw materials used in IOT – Perlite brick appeared to tend towards the higher properties than the ordinary bricks. So, a pilot scale study is taken up based on positive results of laboratory studies.

Thermal conductivity is the material property that determines how fast or how much heat can be transferred through a material for a given temperature difference. Accurate information of a material's thermal conductivity is crucial in heat transfer applications. The thermal conductivity is not always constant. The main factors affecting the thermal conductivity are the density of material, moisture of material and ambient temperature. With increasing density, moisture and temperature the thermal conductivity increases too.

The dense solid materials (Iron ore tailings) tend to have high levels of conductivity, whereas materials with very small matter and large proportion of voids (gas or air bubbles, not large enough to carry heat by convection i.e. Perlite) have the lowest conductivities (www.researchgate.net). Thermal conductivity test is carried out as per ASTM C-177 and IS-3346 on bricks with different combination of materials. The variation of thermal conductivity of samples with IOT, Sand, Perlite and Cement is given in Table 3.19 and the detailed input of thermal conductivity is mentioned in Appendix – A (Table A – 4).

Table 3.19 Thermal conductivity values for different combination of additives

Sl. No	Percentage of Raw materials, %				Avg. Thermal conductivity, W/mk	Decrease in Percentage of Thermal Conductivity with reference to IOT-60%, Sand-20%,Perlite-0% and cement-20%
	IOTs	Sand	Perlite	Cement		
1.	30	60	0	10	1.491	16.47
2.	40	50			1.495	16.25
3.	50	40			1.497	16.13
4.	60	30			1.499	16.02
5.	30	58	2	10	1.220	31.65
6.	40	48			1.236	30.76
7.	50	38			1.259	29.46
8.	60	28			1.290	27.73
9.	30	55	5	10	0.901	49.52
10.	40	45			0.903	49.41
11.	50	35			0.912	48.91
12.	60	25			0.924	48.23
13.	30	55	0	15	1.492	16.41
14.	40	45			1.497	16.13
15.	50	35			1.514	15.18
16.	60	25			1.521	14.79
17.	30	53	2	15	1.271	28.79
18.	40	43			1.278	28.40
19.	50	33			1.291	27.67
20.	60	23			1.310	26.61
21.	30	50	5	15	0.903	49.41
22.	40	40			0.904	49.35
23.	50	30			0.939	47.74
24.	60	20			0.939	47.74

Sl. No	Percentage of Raw materials, %				Avg. Thermal conductivity, W/mk	Decrease in Percentage of Thermal Conductivity with reference to IOT-60%, Sand-20%,Perlite-0% and cement-20%
	IOTs	Sand	Perlite	Cement		
25.	30	50	0	20	1.778	0.39
26.	40	40			1.780	0.28
27.	50	30			1.782	0.17
28.	60	20			1.785	0
29.	30	48	2	20	1.285	28.01
30.	40	38			1.289	27.78
31.	50	28			1.292	27.62
32.	60	18			1.312	26.49
33.	30	45	5	20	0.905	49.30
34.	40	35			0.906	49.24
35.	50	25			0.920	48.46
36.	60	15			0.941	47.28
37.	50	23	7	20	0.7843	56.06

3.5.6 Summary of all properties

The summary of all tests carried out in laboratory are given in Table 3.20.

Table 3.20 Outcome of laboratory studies conducted for the IOT- perlite brick

Sl. No	Percentage of Raw materials, %				Density, kg/m^3	Water absorption, %	Compressive strength, MPa	Thermal conductivity, W/mk
	IOTs	Sand	Perlite	Cement				
1.	30	60	0	10	1754.32	17.99	3.56	1.491
2.	40	50			1789.11	18.30	3.93	1.495
3.	50	40			1843.29	18.91	4.12	1.497
4.	60	30			1898.87	21.30	4.76	1.499

Sl. No	Percentage of Raw materials, %				Density, kg/m^3	Water absorption, %	Compressive strength, MPa	Thermal conductivity, W/mk
	IOTs	Sand	Perlite	Cement				
5.	30	58	2	10	1716.45	19.85	2.62	1.220
6.	40	48			1731.60	20.14	2.69	1.236
7.	50	38			1758.22	20.76	2.75	1.259
8.	60	28			1783.96	22.92	2.83	1.290
9.	30	55	5	10	1236.19	21.66	1.34	0.901
10.	40	45			1237.23	22.32	1.41	0.903
11.	50	35			1242.89	22.67	1.54	0.912
12.	60	25			1284.12	24.01	1.67	0.924
13.	30	55	0	15	1783.44	16.85	5.29	1.492
14.	40	45			1792.72	17.50	6.10	1.497
15.	50	35			1845.79	17.75	6.95	1.514
16.	60	25			1901.96	18.08	7.10	1.521
17.	30	53	2	15	1740.67	18.96	3.18	1.271
18.	40	43			1749.45	19.58	3.28	1.278
19.	50	33			1759.32	20.32	3.30	1.291
20.	60	23			1794.27	22.67	3.56	1.310
21.	30	50	5	15	1287.73	21.00	1.93	0.903
22.	40	40			1290.30	21.96	1.93	0.904
23.	50	30			1310.92	22.16	2.06	0.916
24.	60	20			1337.19	22.90	2.41	0.939
25.	30	50	0	20	1813.85	8.09	8.16	1.778
26.	40	40			1845.79	8.29	9.62	1.780
27.	50	30			1873.12	9.12	10.45	1.782
28.	60	20			1902.48	9.56	11.19	1.784
29.	30	48	2	20	1762.31	13.21	4.30	1.285
30.	40	38			1778.81	13.53	4.45	1.289
31.	50	28			1795.81	14.06	4.58	1.292
32.	60	18			1853.53	14.61	4.72	1.312

Sl. No	Percentage of Raw materials, %				Density, kg/m^3	Water absorption, %	Compressive strength, MPa	Thermal conductivity, W/mk
	IOTs	Sand	Perlite	Cement				
33.	30	45	5	20	1587.36	14.25	3.68	0.905
34.	40	35			1678.32	14.50	3.79	0.906
35.	50	25			1723.43	14.82	3.89	0.920
36.	60	15			1758.19	15.64	4.08	0.941
37.	50	23	7	20	1103.76	15.60	1.79	0.7843

3.6 A Pilot scale study

Pilot scale study is carried out to analyse masonry building to assess the thermal efficiency and the variation of temperature induced in a structure under different intervals of time. Two rooms are constructed, one with IOT and perlite mixed bricks and other with locally available conventional bricks, the description of the building analyzed, the results obtained are presented in the following sections.

3.6.1 Description of the model rooms

To compare the results and to know the efficiency of the IOT – Perlite bricks, two model rooms are constructed one of IOT – Perlite bricks and other conventional fired bricks as shown in Figure 3.8 and Figure 3.9 respectively. These two model rooms are built in similar conditions like in elevation, dimension and height. It is constructed nearby, exposing to the same intensity of light and free from all obstructions.

The room of conventional fired bricks constructed and pointed with cement mortar 1:4 and IOT – Perlite brick room with mortar of IOT, sand, cement and perlite mix as of optimum ratio 50:25:20:5. Both the rooms are laid with plain cement concrete for floor and the roof is covered with asbestos cement sheet. The thickness of the wall is one brick thick having 60cm wide door opening in east and the height of the room is 1.9m with necessary slope.

Figure 3.8 A view of model room constructed with IOT and perlite mixed bricks

Figure 3.9 A view of model room constructed with ordinary bricks

3.6.2 Experimental procedure followed in pilot scale studies

The temperature is measured with two devices i.e. Infrared Thermometer (model CENTER 350 Series) (www.primusthai.com) and Probe Temperature Meter (model V&A Instrument) (www.hertige.com). The wall temperature inside and outside of IOT – Perlite brick wall and ordinary brick walls are measured at morning, afternoon and evening by Infrared Thermometer (Figure 3.11). Atmospheric temperature and the temperature inside the rooms are measured at different intervals of time using Probe Temperature Meter (Figure 3.12). Both of these temperature meters are calibrated with reference to the temperature of human body and water (Figure 3.10).

	
Temperature of water	Temperature of human body

Figure 3.10 Temperature meter calibration with reference to the temperature of human body and water

To measure temperature using infrared thermometer, the unit is pointed at an object and the trigger is pulled. Distance to spot size ratio and field of view is considered. The laser is used for aiming the target for reference. The temperature reading is updated on the LCD. When the trigger is released, the reading will automatically display on the LCD for 10 more seconds. After 10 seconds, this thermometer will power down itself to save its battery. The temperature which is displayed in LCD is an average temperature of the detected region. The temperature reading updated on LCD is noted down for inside and outside of the walls in north, south, east and west directions and measured at three points on the wall i.e. 1 foot below the roof, at center and 1 foot above the floor.

Figure 3.11 Infrared thermometer

Emissivity is a term used to describe the energy emitting characteristics of materials. Most organic materials and painted or oxidized surfaces has an emissivity of 0.98 and the details of infrared thermometer are shown in Table 3.21. Metal surfaces or shiny materials has a lower emissivity (www.primusthai.com).

Table 3.21 General specifications of infrared thermometer

Display	:	4 digit LCD
Field of view	:	8:1
Target indicator	:	Laser spot
Emissivity	:	0.98
Temperature range, ^{o}C	:	-20 ~ 500 (-4 ~ 932 ^{o}F)
Accuracy	:	$\pm$2% of reading
Resolution, ^{o}F	:	0.5^{o}C / 0.5
Repeatability, ^{o}C	:	Within $\pm$1% of reading or $\pm$1 (2^{o}F)

Probe temperature meter is the digital temperature meter, used to accurately measure internal temperature (i.e. room temperature) and ambient temperature (i.e. atmospheric temperature). Probe temperature meter will ON by pressing the ON/ OFF key during power off status will turn on the system, vice versa. All symbols will be displayed in LCD for two seconds after power on and then the current temperature will be displayed. The temperature unit ^{o}C is present after turn on. During measurement can switch it to ^{o}C/ ^{o}F key.

Figure 3.12 Probe temperature meter

The probe is extended to measure the internal temperature of an object. Probe is to be inserted at least 12mm into the target and then the device will measure the core temperature automatically. The probe comes to equilibrium with the object being measured and the reading in LCD reaches almost steady. Temperature is noted down periodically and stopped at a point when it is in equilibrium. To get a better accuracy, it is measured for a moment after the reading is almost steady to ensure that the probe has fully stabilized and reached equilibrium with the object. Auto power off time is set to 8 min; it will enter into sleep status if there is no action to any key in 8 min after power on. The set time will be re-calculated if any key is pressed. To cancel the auto power off function ^{o}C/ ^{o}F key is pressed to power on. The specifications of probe temperature meter are mentioned in Table 3.22.

Table 3.22 General specifications of probe temperature meter

Display	:	$^{1}/_{3}$ duty, ½ bias 3x13 LCD
Measurement period, sec	:	1 time/ 2
Auto power off time, min	:	8
Temperature range, ^{o}C	:	-50 to 270 (-58 to 518^{o}F)
Accuracy, ^{o}C	:	-50~200;±(reading x 1.5% +1^{o}C) 200~270;±(reading x 2.0% +4^{o}C)
Resolution, ^{o}C	:	0.1 (-50~ 200) 1 (200~ 270)

Two rooms are constructed using IOTs and Perlite brick and other of ordinary brick room (Figure 3.13). After noting the ambient temperature, the temperature of walls on all four sides North wall (NW), South wall (SW), East wall (EW) and West wall (WW) are measured before plastering. The temperature of the roof was noted down.

Ordinary brick wall | IOT – Perlite brick wall

Figure 3.13 Temperature measurements of atmosphere and outside wall

The two models rooms i.e. IOT – Perlite brick and other of ordinary brick room are plastered (Figure 3.14). To the IOT – Perlite brick room, mortar is used for plastering of wall is of the same proportion of raw materials which is used for preparing IOT – Perlite bricks. To the ordinary brick room, cement mortar of 1:4 (Cement: sand) is used for the plastering. The process of noting the temperature of both rooms are done similar to the measurement of temperature before plastering of two model rooms.

Ordinary brick room | IOT – Perlite brick room

Figure 3.14 Model rooms of ordinary and IOT – perlite brick room after plastering

A pilot scale study is taken up to assess the effectiveness of IOT- perlite bricks in actual filed conditions but in a mini scale. Two model brick rooms are constructed and the internal and external temperatures are measured to determine the thermal conductivity of IOT - Perlite brick room by comparing the ordinary brick room. Model brick rooms are tested before plastering and after plastering. Plaster with IOT and perlite presented better performance due to their low thermal conductivity. These are cost effective and sustainable solutions to passively improve the thermal performance of buildings, as well as to mitigate the impacts of disposal of these residues.

The use of IOT and perlite in bricks reduces the thermal conductivity of the outside wall as these materials arrest the atmospheric temperature from outside compared to the ordinary wall.

One of the trial results of room temperature taken for morning (8am to 10am), midday (12pm to 3pm) and evening (4pm to 6pm) at a regular interval of 15 minutes is given in the following section.

3.6.3 Measurement of temperature from 8am to 10am before plastering

Temperature readings are recorded for two model rooms one with IOTs - Perlite mix bricks and other with ordinary bricks, at 8am to10am on four walls, one set of reading is shown in Table 3.23 and the rest are given in Appendix B (Table B – 1).

Table 3.23 Temperature measured from 8am to 10am for IOTs – perlite brick wall and ordinary brick wall

	IOT – Perlite Bricks						Date	Time	Ordinary Bricks						Date	Time	Temperature measured keeping the door closed
	Outside Wall, °C			Inside Wall, °C					Outside Wall, °C			Inside Wall, °C					
	T	M	B	T	M	B			T	M	B	T	M	B			
NW	25.50	25.50	25.00	22.00	21.50	21.50	14-06-2019	10:07 am	29.50	29.50	29.00	26.50	26.00	25.00	14-06-2019	10:00 am	
EW	26.00	26.00	25.50	22.50	21.50	21.00			30.00	30.00	29.50	27.00	26.50	26.00			
SW	25.50	25.50	25.00	21.50	21.00	20.50			29.50	29.00	28.00	26.00	25.50	25.00			
WW	25.00	24.50	24.00	21.00	20.50	20.00			29.00	28.50	28.00	25.50	25.00	24.50			
Roof				b/w 29.50 & 31.00					Roof			b/w 30.50 & 32.00					
Room Temperature				25.00					Room Temperature			27.50					
Atmospheric Temperature surrounding the constructed rooms – 29.00^{0}C																	

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre of the wall)
B - Bottom (Temperature measured 1foot above the floor)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

3.6.4 Measurement of temperature from 12pm to 3pm before plastering

For the constructed two model rooms one with IOT and Perlite mix bricks and other with ordinary bricks, following are the temperature readings observed from 12pm to 3pm for four side walls (Table 3.24). Six temperature measurements are taken for midday, in which one of the measurements is mentioned in below table and the rest are given in Appendix – B (Table B - 2).

Table 3.24 Temperature measured from 12pm to 3pm for outside and inside of IOTs – perlite bricks and ordinary bricks wall

	IOT Bricks						Date	Time	Ordinary Bricks						Date	Time	Temperature measured keeping the door closed
	Outside Wall, ^{o}C			Inside Wall, ^{o}C					Outside Wall, ^{o}C			Inside Wall, ^{o}C					
	T	M	B	T	M	B			T	M	B	T	M	B			
NW	28.50	29.00	27.50	25.50	24.50	23.50	29-06-2019	12:08 pm	32.50	31.50	31.00	28.00	26.50	26.00	29-06-2019	12:00 pm	
EW	28.50	28.00	28.50	26.00	25.00	24.00			32.00	32.00	31.50	28.00	26.50	26.00			
SW	29.00	28.50	27.00	25.00	24.50	23.00			32.50	31.50	31.50	27.50	26.00	25.50			
WW	28.00	27.50	25.50	25.50	24.50	23.00			30.00	31.00	30.00	27.00	26.00	25.00			
Roof				b/w 38.00 & 43.50					Roof			b/w 36.50&39.00					
Room Temperature				27.50					Room Temperature			29.00					

Atmospheric Temperature surrounding the constructed rooms – 30.00^{0}C

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre of the wall)
B - Bottom (Temperature measured 1foot above the floor)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

3.6.5 Measurement of temperature from 4pm to 6pm before plastering

For the constructed two model rooms one with IOT and Perlite mix bricks and other with ordinary bricks, following are the temperature readings observed from 4pm to 6pm for four side walls (Table 3.25). The temperature of IOT – Perlite and ordinary bricks are taken for inside and outside walls, room and atmospheric temperature in 6 no’s, in which one is mentioned below table and remaining are listed in Appendix-B (Table B-3).

Table 3.25 Temperature measured from 4pm to 6pm on IOT – perlite brick wall and ordinary brick wall

	IOT Bricks						Date	Time	Ordinary Bricks						Date	Time	Temperature measured keeping the door closed
	Outside Wall, ^{o}C			Inside Wall, ^{o}C					Outside Wall, ^{o}C			Inside Wall, ^{o}C					
	T	M	B	T	M	B			T	M	B	T	M	B			
NW	27.50	27.50	27.00	25.50	26.50	26.00	15-06-2019	6:05 pm	30.50	30.50	29.50	29.00	29.50	28.00	15-06-2019	5:55 pm	
EW	26.00	26.50	26.50	25.00	26.00	25.00			30.00	29.50	28.00	29.00	29.00	27.50			
SW	27.50	27.50	26.50	26.00	26.00	26.00			31.00	30.00	27.50	30.50	29.50	27.00			
WW	27.50	27.50	27.00	26.00	26.50	26.00			31.50	30.50	30.00	31.00	30.00	29.00			
Roof				b/w 28.00 & 29.00					Roof			b/w 28.50 & 30.50					
Room Temperature				26.50					Room Temperature			28.00					
Atmospheric Temperature surrounding the constructed rooms - 28^{0}C																	
T - Top (Temperature measured 1 foot below the top) M - Middle (Temperature measured at centre of the wall) B - Bottom (Temperature measured 1foot above the floor)									NW - North Wall EW - East Wall SW - South Wall WW - West Wall								

3.6.6 Temperature measurement of the room at 5minutes interval before plastering

Temperature is a physical property of matter that quantitatively expresses common notions of hot and cold. Room temperature and ambient temperature are directly affected by the heating and cooling system. The solar energy received by any region varies with time of day, with seasons, and with latitude that causes temperature variations. Hence influence of time on room temperature is determined, to know the thermal behaviour causing the change in IOT – Perlite brick room and the readings of IOT – Perlite brick room and ordinary brick room is noted for every 5 minutes interval (Table 3.26).

Table 3.26 Temperature measurement at 5minutes interval before plastering

Time	**Ambient Temperature,** ^oC	**Ordinary brick room,** ^oC	**IOT – Perlite brick room,** ^oC
0	35.80	35.70	34.60
5	34.50	34.60	33.50
10	35.00	35.00	33.90
15	35.10	35.50	34.20
20	36.00	36.00	34.30
25	35.00	35.70	34.60
30	35.60	35.80	34.50
35	35.60	35.60	34.20
40	35.60	35.80	34.00
45	35.10	35.70	34.40
50	35.50	36.10	34.70
55	35.30	36.70	35.65

The two rooms are plastered with 12mm thick mortar on both sides of the wall. The room of ordinary brick room with cement mortar and IOTs and perlite brick room with the mortar same as of material and proportion of that brick. The quality of mortar obtained in IOTs and Perlite brick wall plastering is same as of the quality of its brick. The room temperature is measured with probe temperature meter by closing the door. The comparison of temperature difference is done with ambient temperature, IOTs and Perlite brick room and ordinary brick room. The test is done after the plastering to ensure further reduction in room temperature and to obtain less heat and minimize the energy consumption in air conditioning system.

3.6.7 Measurement of temperature from 8am to 10am after plastering

The same procedure is followed to measure the temperature of outside of the walls, inside of the walls and room of IOT-perlite brick and ordinary brick. Here one set of the reading is presented in the Table 3.27 and rest of the trials measured from 8 am to 10am are given in Appendix - C (Table C-1).

Table 3.27 Temperature measured from 8am to 10am on IOT – perlite brick wall and ordinary brick wall

	IOT Bricks						Date	Time	Ordinary Bricks						Date	Time	Temperature measured keeping the door closed
	Outside Wall, ^{o}C			Inside Wall. ^{o}C					Outside Wall, ^{o}C			Inside Wall, ^{o}C					
	T	M	B	T	M	B			T	M	B	T	M	B			
NW	23.50	23.50	22.50	23.50	22.00	20.50	24-09-2019	10:30 am	24.50	24.00	23.00	24.00	23.00	22.50	24-09-2019	10:40 am	
EW	25.00	24.50	23.50	24.50	23.50	22.00			26.00	25.50	24.00	26.00	25.00	23.50			
SW	30.00	31.00	31.50	28.00	27.00	25.50			30.50	32.00	32.50	29.50	29.50	28.00			
WW	28.00	27.50	26.00	25.50	24.50	22.50			29.00	28.50	28.00	28.00	27.00	26.00			
Roof				30.50 ^{o}C – 38.00 ^{o}C					Roof			35.50 ^{o}C – 38.50 ^{o}C					
Room Temperature				25.50 ^{o}C					Room Temperature			28.00 ^{o}C					
Atmospheric Temperature surrounding the constructed rooms - 30.00 ^{o}C																	

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre of the wall)
B - Bottom (Temperature measured 1foot above the floor)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

3.6.8 Measurement of temperature from 12pm to 3pm after plastering

Several sets of the temperature of walls of IOT-perlite brick room and ordinary brick room, observed from 12pm to 3pm for four side walls and room temperature are measured and one of the best readings obtained is mentioned in Table 3.28. The remaining readings of temperature of walls of IOT – Perlite and ordinary brick room at different time are listed in Appendix – C (Table C – 2).

Table 3.28 Temperature measured from 12pm to 3pm on IOT – perlite brick wall and ordinary brick wall

	IOT Bricks						Date	Time	Ordinary Bricks						Date	Time	Temperature measured keeping the door closed
	Outside Wall, ^{o}C			Inside Wall, ^{o}C					Outside Wall, ^{o}C			Inside Wall, ^{o}C					
	T	M	B	T	M	B			T	M	B	T	M	B			
NW	32.50	31.00	28.00	31.00	29.00	26.50	27-09-2019	1:20 pm	33.50	32.00	31.50	32.50	30.50	30.50	27-09-2019	1:25 pm	
EW	30.00	29.00	28.00	28.50	27.00	27.00			30.50	29.50	29.00	29.50	28.00	28.00			
SW	32.50	33.00	33.50	30.00	31.50	31.00			33.00	33.50	34.50	31.00	32.00	33.50			
WW	30.50	31.00	31.50	28.00	29.50	29.50			31.50	31.50	32.50	30.50	30.00	31.00			
Roof				40.50 ^{o}C – 42.00 ^{o}C					Roof			41.50 ^{o}C – 43.50 ^{o}C					
Room Temperature				31.00 ^{o}C					Room Temperature			33.50 ^{o}C					
Atmospheric Temperature surrounding the constructed rooms – 34.50^{o}C																	

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre of the wall)
B - Bottom (Temperature measured 1foot above the floor)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

3.6.9 Measurement of temperature from 4pm to 6pmafter plastering

The temperature readings of IOT-perlite brick room and ordinary brick room, observed from 4pm to 6pm for four side walls and room temperature are given in Table 3.29. The remaining readings of temperature of IOT – Perlite and ordinary brick room at different time are listed in Appendix – C (Table C – 3).

Table 3.29 Temperature measured from 4pm to 6pm on IOT – perlite brick wall and ordinary brick wall

	IOT Bricks						Date	Time	Ordinary Bricks						Date	Time	Temperature measured keeping the door closed
	Outside Wall, ^{o}C			Inside Wall, ^{o}C					Outside Wall, ^{o}C			Inside Wall, ^{o}C					
	T	M	B	T	M	B			T	M	B	T	M	B			
NW	30.00	29.50	28.00	27.50	27.00	25.50	30-09-2019	4:10 pm	30.50	30.00	29.00	29.50	29.00	28.00	30-09-2019	4:15 pm	
EW	30.50	29.00	27.50	28.00	26.50	25.00			30.00	29.00	28.00	29.00	27.50	27.00			
SW	31.50	32.50	33.00	29.00	30.00	30.50			32.50	33.00	33.50	31.50	32.00	32.50			
WW	31.00	32.00	34.00	28.50	29.00	31.50			31.50	33.00	35.00	30.50	32.00	34.00			
Roof				38.00 ^{o}C – 39.00 ^{o}C					Roof			39.00 ^{o}C – 40.00 ^{o}C					
Room Temperature				29.00 ^{o}C					Room Temperature			31.50 ^{o}C					
Atmospheric Temperature surrounding the constructed rooms – 34.00^{o}C																	

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre of the wall)
B - Bottom (Temperature measured 1foot above the floor)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

3.6.10 Temperature measurement of the room at 5minutes interval after plastering

Temperature measured with reference to time in an interval of 5 minutes for 55 minutes, after free ventilation was closed (Table 3.30). Influence of time on room temperature is determined after plastering of IOT- perlite brick room and ordinary brick room, to know the thermal behaviour causing the change in both the rooms.

Table 3.30 Temperature measurement at 5minutes interval after plastering

Time	**Ambient Temperature,** ^oC	**Ordinary brick room,** ^oC	**IOT – Perlite brick room,** ^oC
0	33.80	33.50	31.20
5	33.40	33.80	31.40
10	33.50	33.80	31.50
15	33.80	33.60	31.50
20	33.60	33.50	31.50
25	33.50	33.50	31.30
30	33.20	33.60	31.20
35	33.50	33.70	31.20
40	33.80	33.80	31.30
45	33.60	33.60	31.20
50	33.80	33.50	31.00
55	33.50	33.40	30.90

CHAPTER-4

CHAPTER 4

RESULTS AND ANALYSIS

Bricks in this research work are made from Iron Ore Tailings (IOT) and Perlite, sand and cement without firing. At least 6 samples are used for each test for all groups listed previously in Table 3.14, 3.15 & 3.16 and the average values are presented and discussed in this Chapter. The investigated and reported physical and mechanical properties are density, water absorption, compressive strength, efflorescence, thermal conductivity and measurement of room temperature for different interval of time in pilot scale study. Also, regression analysis for various mix proportions considered in the present research study are discussed in this chapter.

This chapter gives the details of analysis of experiments carried out.

4.1 Optimum Percentage of Raw Materials

Bricks are prepared by keeping cement as constant at 10%, 15% and 20% by adding iron ore tailings in proportion 30%, 40%, 50% and 60% and perlite in proportions of 2% and 5%. The tests are conducted such as compressive strength, water absorption, efflorescence and thermal conductivity for all the varied proportion to obtain a better result

4.1.1 Density

Density of each brick is determined as per IS 1077:1963 and the average of at least 6 samples is reported. Figure 4.1 shows when iron ore tailings in bricks increased from 30 to 60%, density also increased gradually (1754.32 Kg/m^3 – 1898.87 Kg/m^3), later it is slightly/ gradually reduced for all percentages of perlite at a fixed percentage of 10% cement content i.e. from 0% to 5% of perlite, density reduced from 1843.29 Kg/m^3 to 1242.89 Kg/m^3. Similar trend is observed in Figure 4.2 and Figure 4.3 for 15% and 20% cement content respectively. So, it can be concluded that addition of perlite drastically decreases the density of brick.

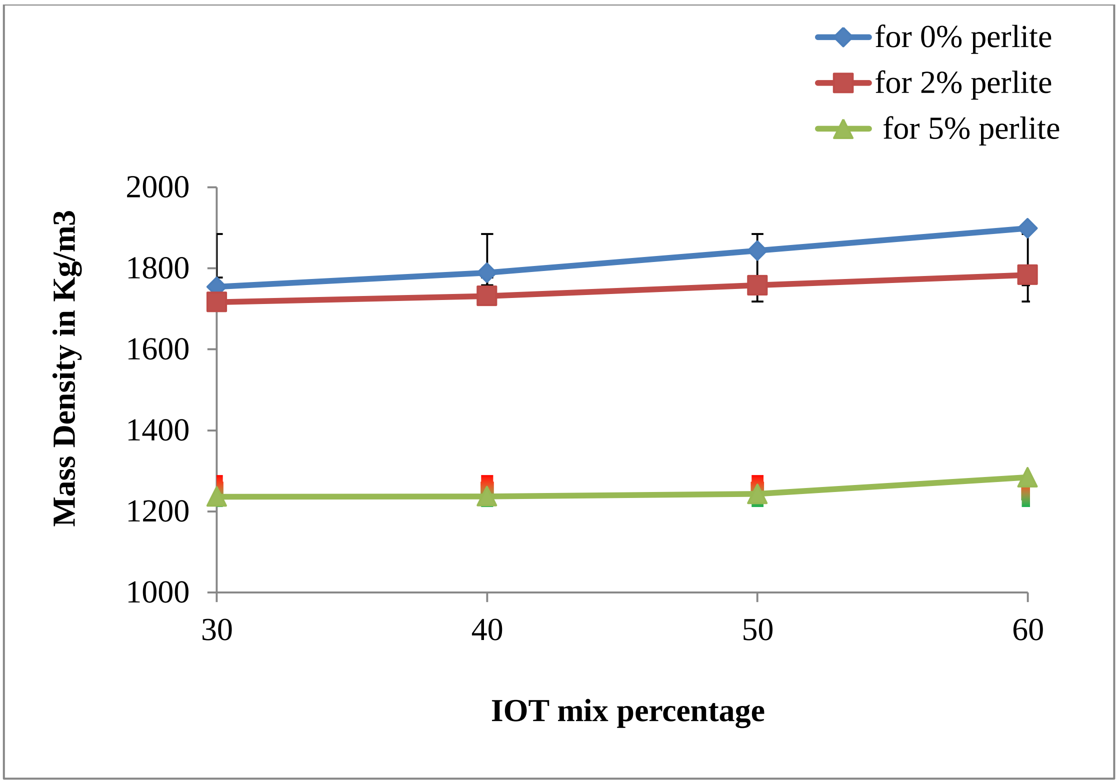

Figure 4.1 Density of bricks with 10% cement for different IOTs mix percentage

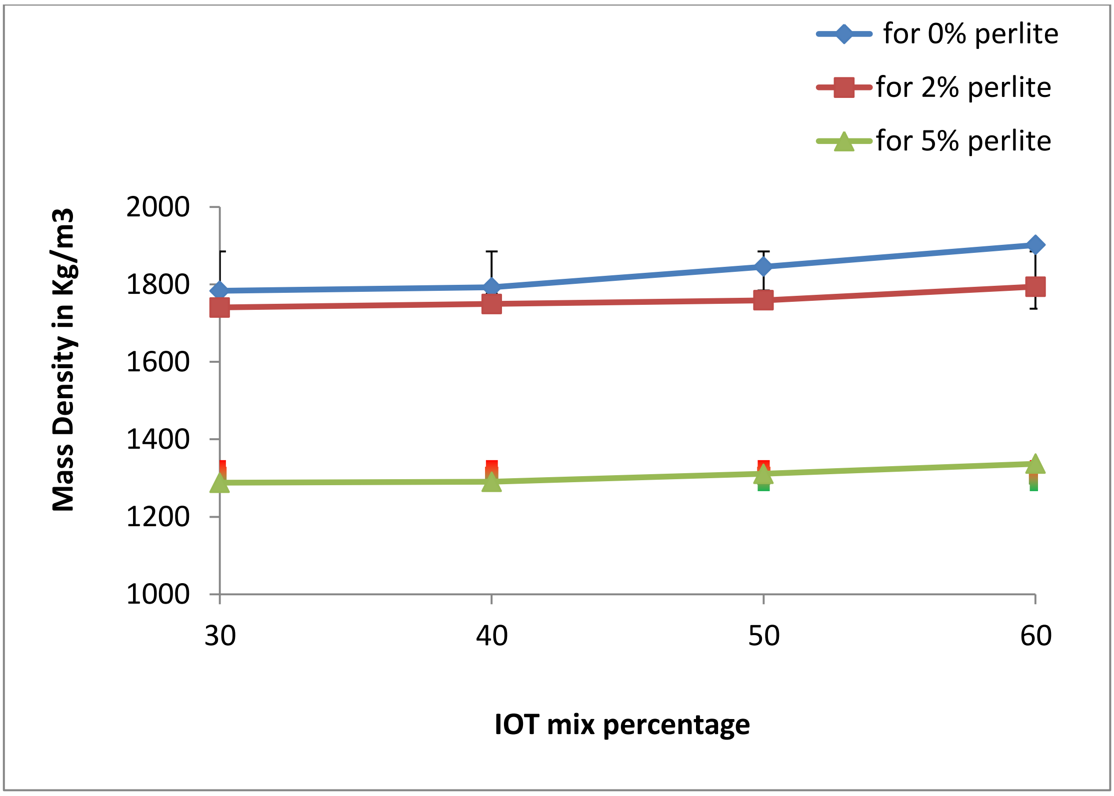

Figure 4.2 Density of bricks with 15% cement for different IOTs mix percentage

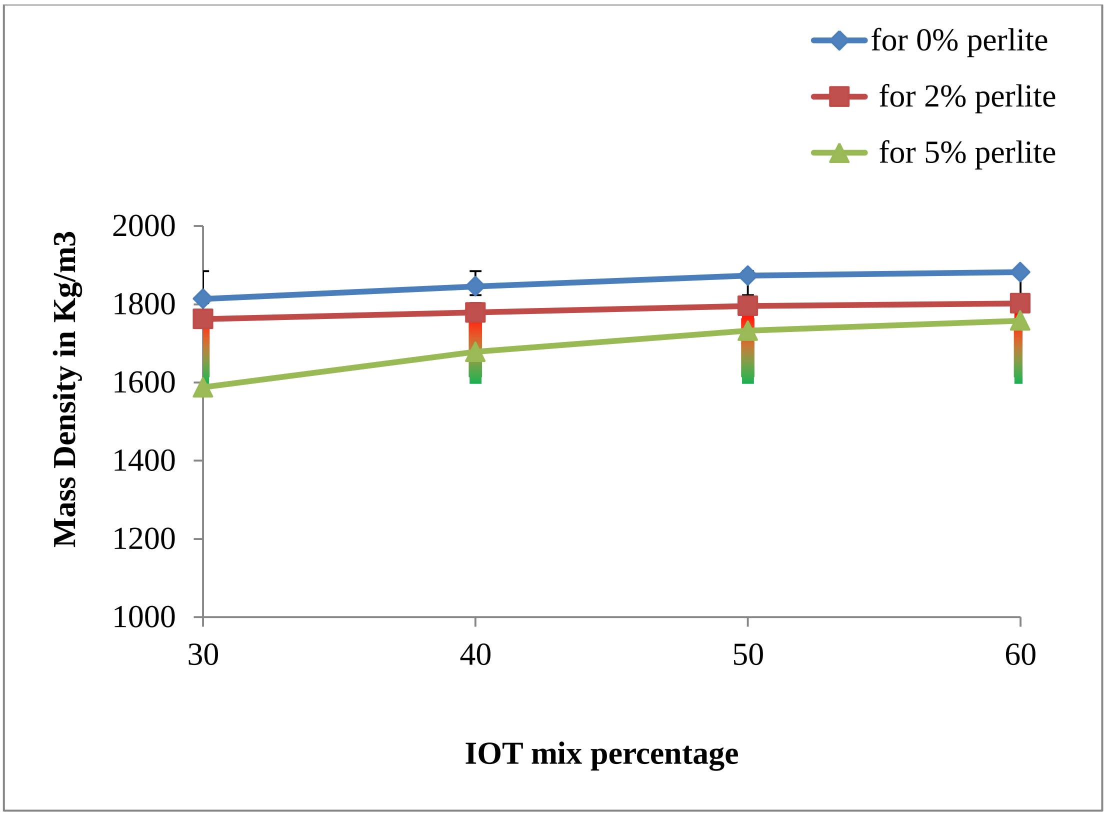

Figure 4.3 Density of bricks with 20% cement for different IOTs mix percentage

4.1.2 Water absorption

According to IS3495 (Part II): 1992, water absorption should not be more than 20% for 24 hours immersion. Slight increase in water absorption is noticed when there is an increase in IOT and higher percentage of water absorption is found when perlite is added as it is a porous structure. When cement addition is increased from 10% to 20% in the interval of 5%, water absorption decreased drastically. Figure 4.4 shows the trend of water absorption for 10% of cement content, with increase in IOT percentage. Figure 4.5 and 4.6 also shows as IOT increased from 30 to 60%, water absorption also increased due to the increase in surface area of iron ore tailings. Although the perlite content goes on increasing (0-5%) water absorption gradually increased, as perlite has a relatively high water content and at 20% cement addition water absorption was favourable by satisfying the IS code.

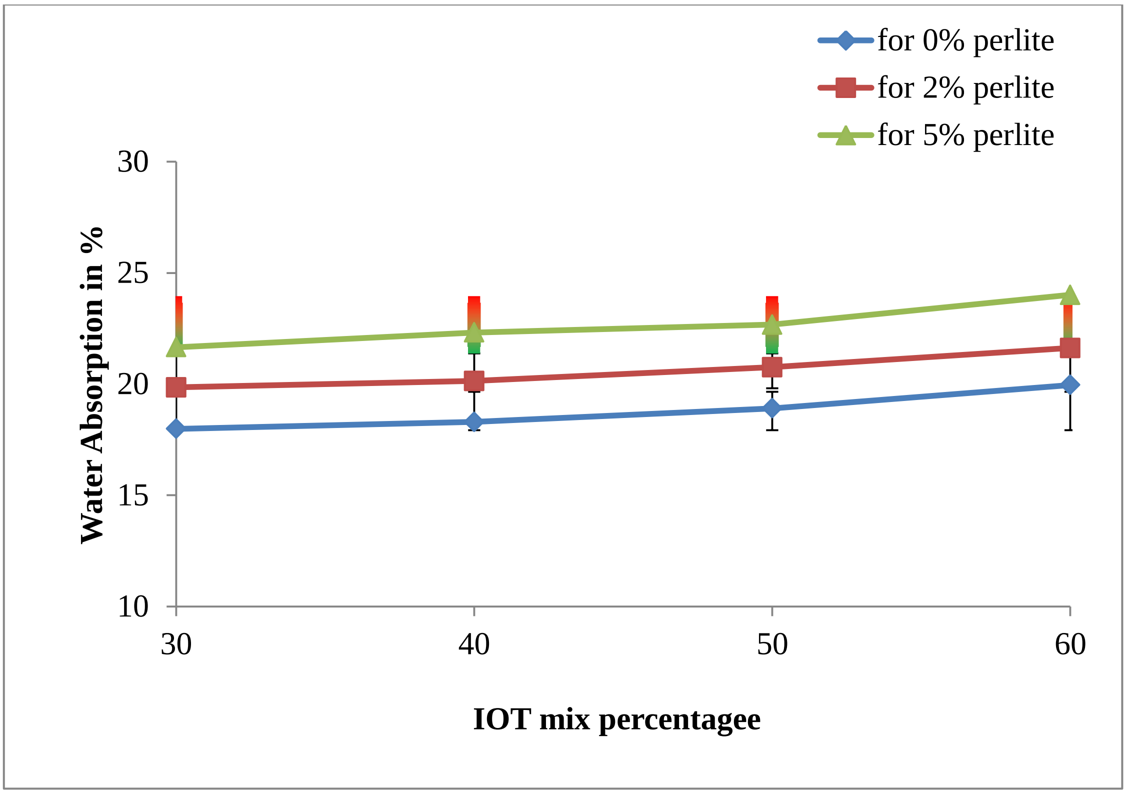

Figure 4.4 Water absorption of bricks for 10% cement for different IOTs mix percentage

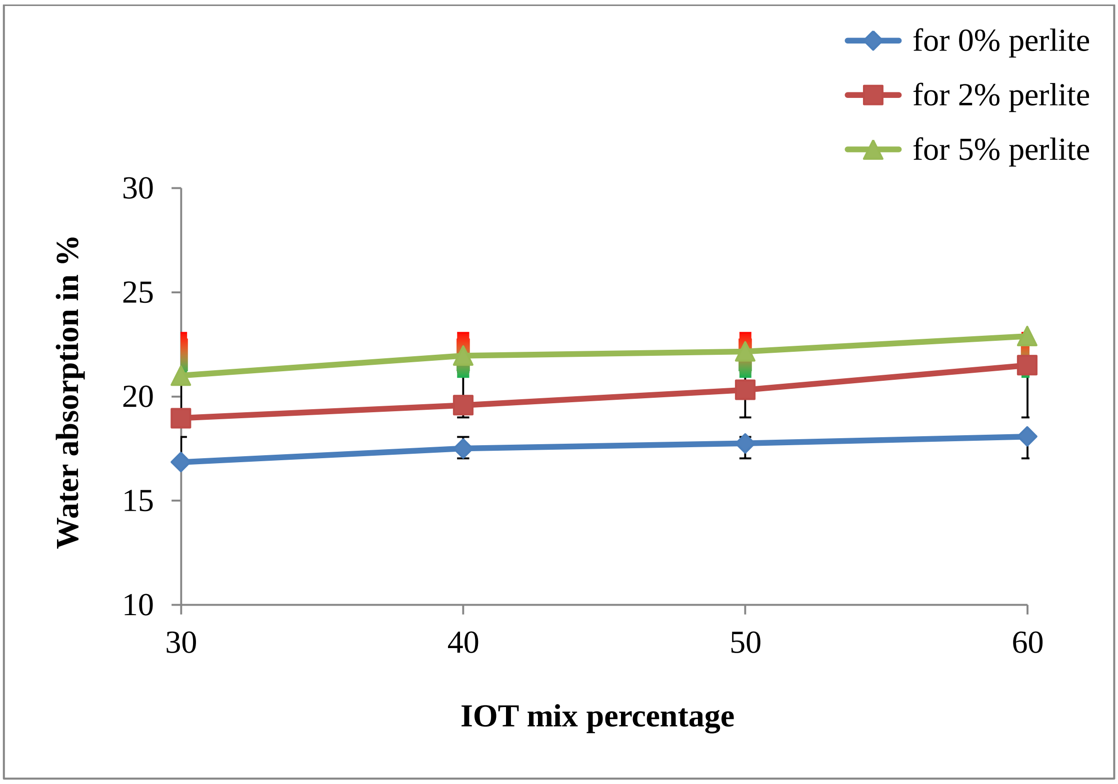

Figure 4.5 Water absorption of bricks for 15% cement for different IOTs mix percentage

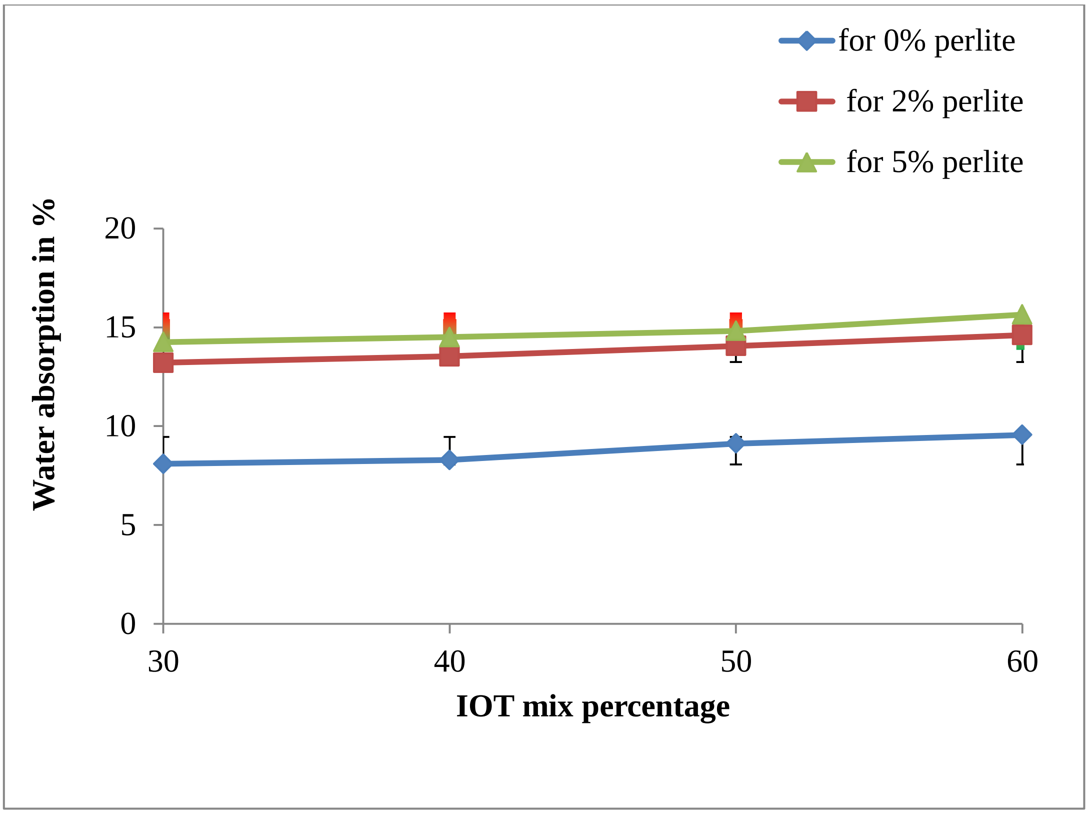

Figure 4.6 Water absorption of bricks for 20% cement for different IOTs mix percentage

4.1.3 Compressive strength

Compressive strength is the more common performance parameter measured and used to study the properties of brick. It gives an idea about the mechanical properties of brick. As per IS 3495:1992 Part I, the minimum compressive strength of bricks should be 3.5MPa. Figure 4.7 shows that the compressive strength increased as the IOTs percentage increased from 30 to 60%, at a fixed percentage of 10% cement content. But as the perlite percentage increased from 0 to 5%, compressive strength decreased for all IOTs mixes. Similar trend is observed in Figure 4.8 and 4.9 for 15% and 20% cement content respectively. So, it can be stated that maximum of 50% IOTs mix with 20% cement gives better compressive strength and 5 % perlite addition will not compromise on the required compressive strength. Though the perlite addition reduces compressive strength but reduces density and thermal conductivity, which are advantageous.

Infact, a few bricks were casted with 20% cement combination and 7% perlite also, but they have resulted less than IS code required compressive strength i.e. 3.5MPa. So, the influence of 7% perlite is not included in the study.

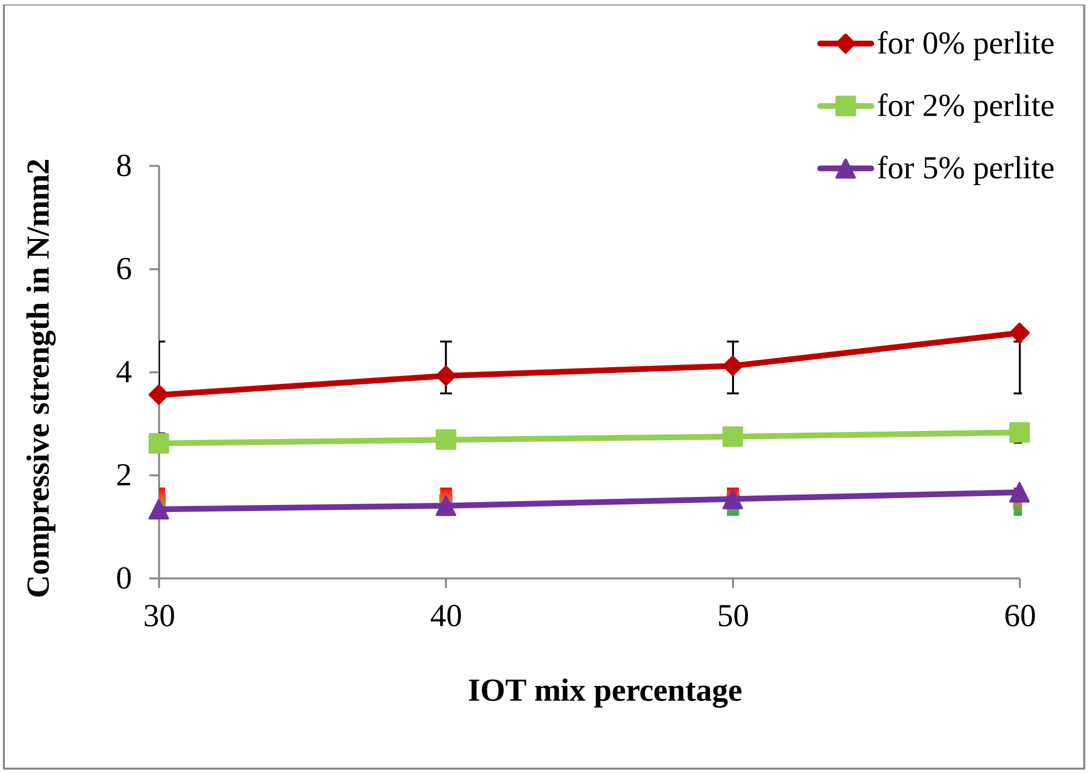

Figure 4.7 Compressive strength of bricks with 10% cement for different IOTs mix percentage

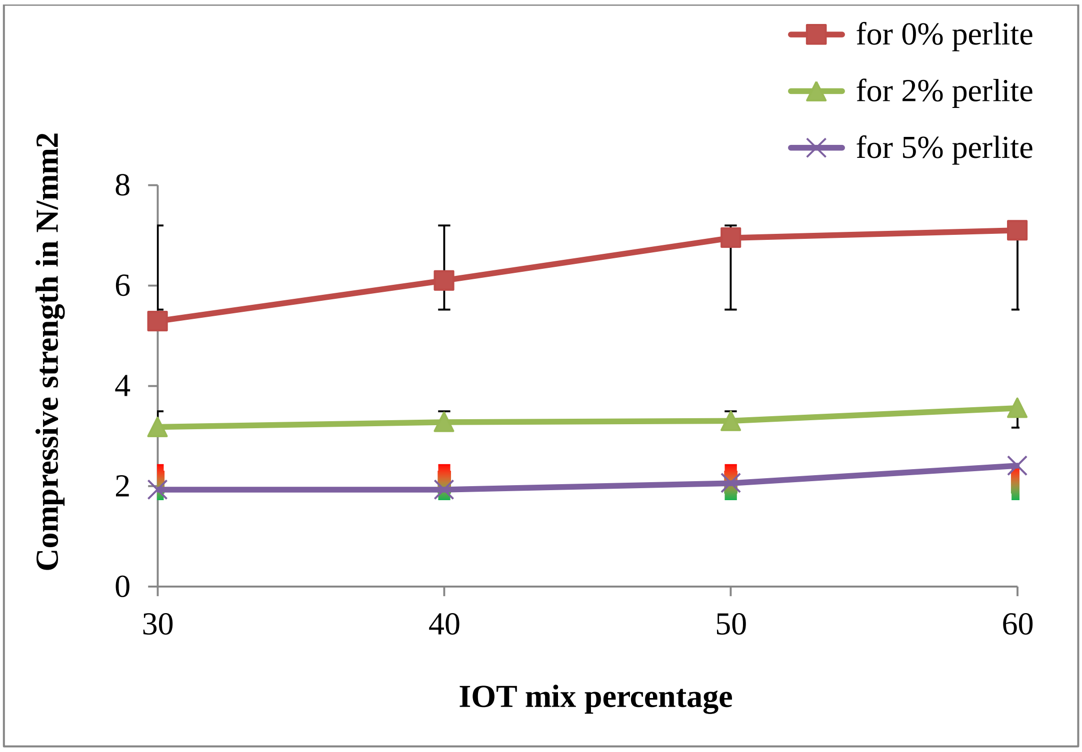

Figure 4.8 Compressive strength of bricks with 15% cement for different IOTs mix percentage

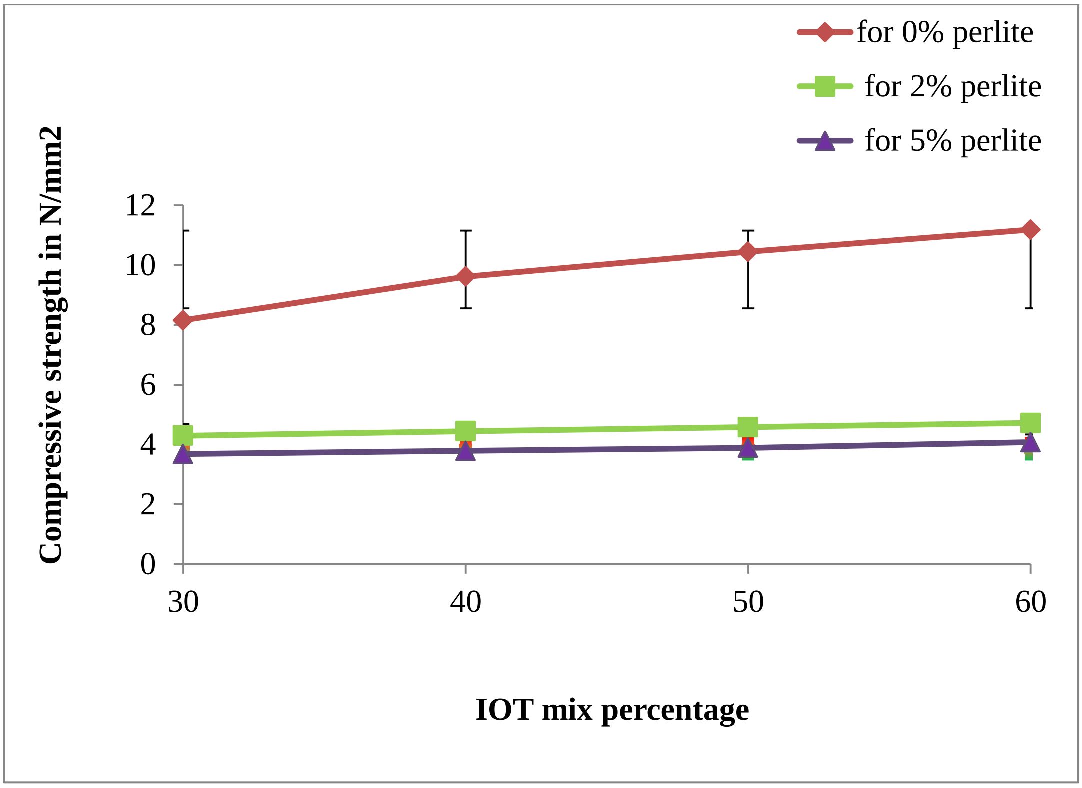

Figure 4.9 Compressive strength of bricks with 20% cement for different IOTs mix percentage

4.1.4 Efflorescence

Efflorescence test is carried out as per IS 3495:1992 Part III. The result obtained for this test is ‘Nil’, when brick is containing 5% of Perlite, 50% of IOTs and 20% cement, almost no perceptible deposit of efflorescence is observed. When there is no Perlite in brick, presence of efflorescence is observed. While efflorescence is not a risk structurally, but it affects the appearance of a building, particularly it features coloured brickwork. It concludes that presence of perlite in brick shows no efflorescence, which can be used for brickwork and reduces the maintenance cost, which is an added advantage.

4.1.5 Thermal conductivity

Thermal conductivity tests are conducted simultaneously with other tests. Many trials are done in order to confirm the influence of perlite. In general, it is found that as perlite percentage increases, the thermal conductivity decreases. Among the tests conducted, the highest value of the thermal conductivity i.e., 1.7847 W/mk is obtained for samples produced with 60% IOT, 20% sand, 0% perlite and 20% cement. As perlite content increased thermal conductivity decreased. For 0%, 2% and 5% Perlite, the reduction in thermal conductivity are noted as 1.778 W/mk, 1.285 W/mk and 0.905 W/mk, respectively at 30% IOT and 20% Cement. In the entire mix, thermal conductivity reduced, when perlite percentage 0 to 5% increased for all IOT percentage of IOT and cement. This describes that the thermal conductivity will decrease when there is increase in Perlite content.

Figure 4.10 shows that the thermal conductivity increased as the IOT percentage increased from 30 to 60%, later it is reduced for all percentages (0% -5%) of perlite at a fixed percentage of 10% cement content. As the perlite percentage increased from 0 to 5%, thermal conductivity decreased for all IOT mixes. Similar trend is observed in Figure4.11 and Figure 4.12 for 15% and 20% cement content respectively. So, it can be stated that perlite is the best thermal insulator which have the lowest thermal conductivity and combination of 50% IOT mix, 5 % perlite and 20% cement addition will give better thermal conductivity by keeping in view of other properties such as density, compressive strength and water absorption.

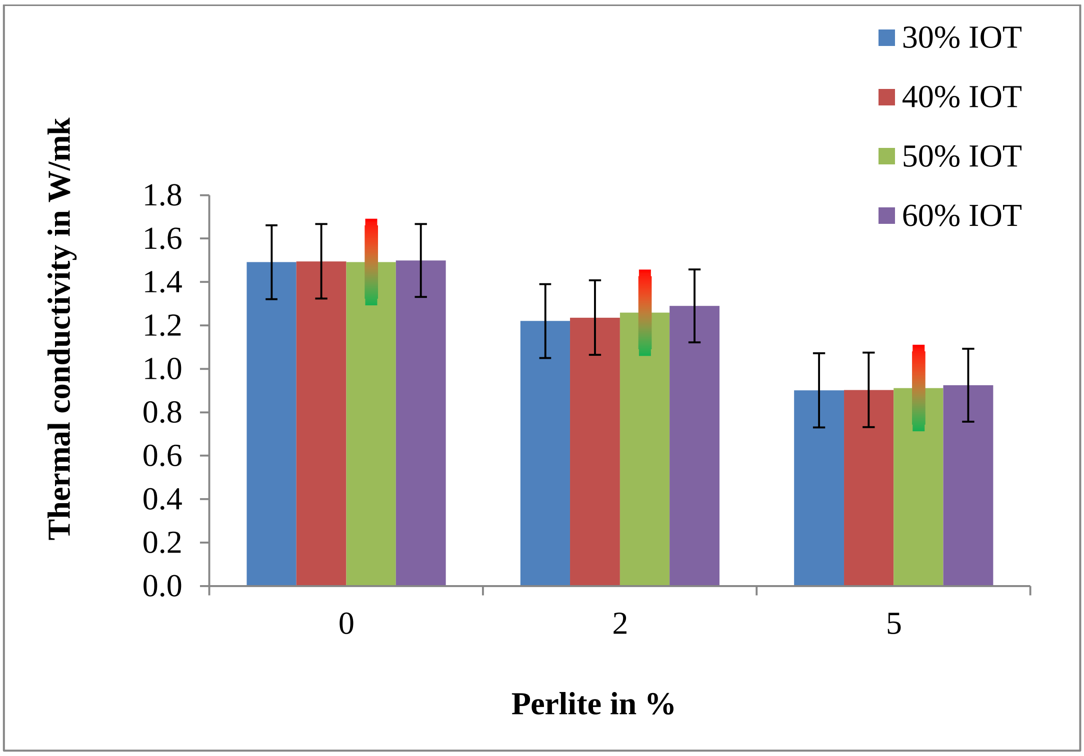

Figure 4.10 Thermal conductivity of bricks with 10% cement for different IOTs mix percentage

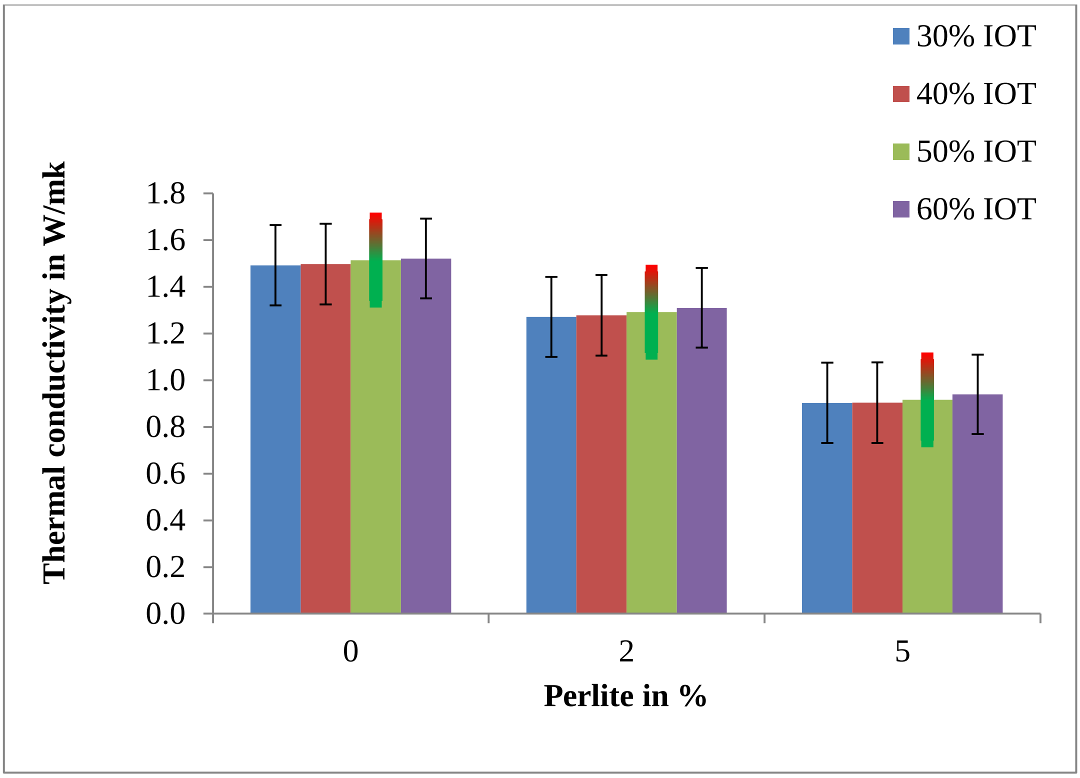

Figure 4.11 Thermal conductivity of bricks with 15% cement for different IOTs mix percentage

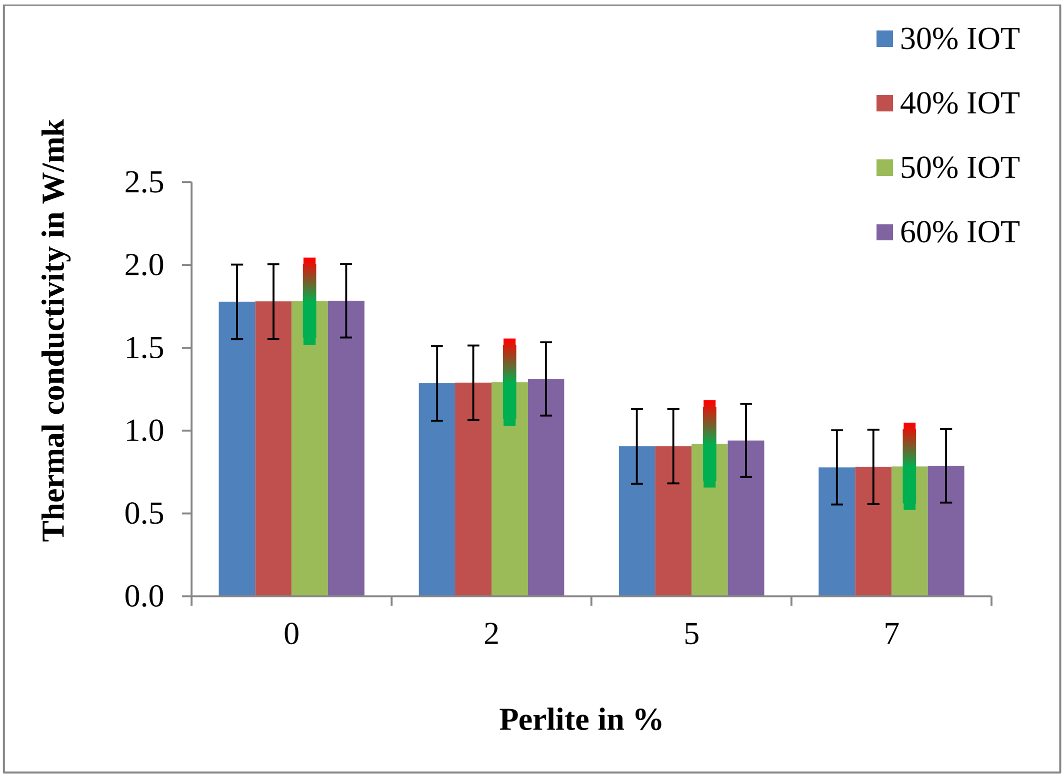

Figure 4.12 Thermal conductivity of bricks with 20% cement for different IOTs mix percentage

Based on laboratory scale studies, it can be concluded that 50:25:20:5 (IOT: Sand: Cement: Perlite) mix gives optimum results. So, in order to prove the effectiveness of optimum mix bricks, a pilot scale study is carried out.

These observations are in line with the findings of Arunraja, et al., (2017) with lightweight bricks of size 190mmx90mmx90mm using perlite and lime in various ratios like 70:30, 75:25, 80:20 and 85:15. This has resulted 3.3 MPa compressive strength and the present study obtained 3.89MPa which satisfies the IS code.

4.2 Pilot Scale Study

A pilot scale study is carried out to assess the effectiveness of iron ore tailings and perlite brick. Two rooms are constructed one with IOTs and perlite bricks and other with locally available fired clay brick. Temperatures of model rooms are measured in two cases one is before plastering and other after plastering.

4.2.1 Thermal efficiency of IOT-perlite bricks vs conventional bricks based on the temperature measurement before plastering

The model rooms are measured at morning, afternoon and evening before plastering and also the influence of time on room temperature of IOT- perlite brick and ordinary brick are measured.

4.2.1.1 Measurement of temperature in the morning from 8am to 10am

The temperature reading is taken in different phases during 8am to 10am; of the outside walls of the IOT – Perlite brick and ordinary bricks, by taking the readings 1 foot below the roof level (Figure 4.13), at middle of the wall (Figure 4.14) and at 1 foot above the floor of the wall (Figure 4.15) in different directions NW: North side Wall, EW: East side Wall, WW: West side Wall, SW: South side Wall). Similarly, the variation in temperature inside walls of the IOT – Perlite bricks and ordinary bricks are shown in Figure 4.16, Figure 4.17 and Figure4.18. Temperature is measured through infrared thermometer device. The below graphical representation shows the variation in temperature, for the walls constructed from IOT mix perlite bricks and ordinary bricks.

From 8am to 10am ambient temperature at the surroundings of the rooms is measured and it was 29^{o}C. The readings are taken on the walls of all sides (N, E, W and S) to check the heat transfer at all sides of the walls, whereas heat is the form of energy transfer from high temperature location to a low temperature location. The sun rays fall on eastern side of the wall during forenoon, so the temperature at outside of east wall is more compared to other sides. On an average, IOT – Perlite bricks walls resulted in 3 to 4^{0}C less in temperature than ordinary bricks.

It is also observed that temperature of the IOT – Perlite brick walls in outer surface is less by 10% than ambient temperature, which is only 0-2% in the case of ordinary brick walls. The temperature of IOT – perlite brick walls from outer to inner surface is reduced by 13%, but in case of ordinary bricks it is 10%. This concludes the ambient temperature is arrested by outer surface of the IOT – Perlite brick walls by more than 10% and inner surface is atleast 3% less compared to that of ordinary brick walls. The room temperature of IOT – Perlite bricks is less by 7% compared to that of ordinary bricks.

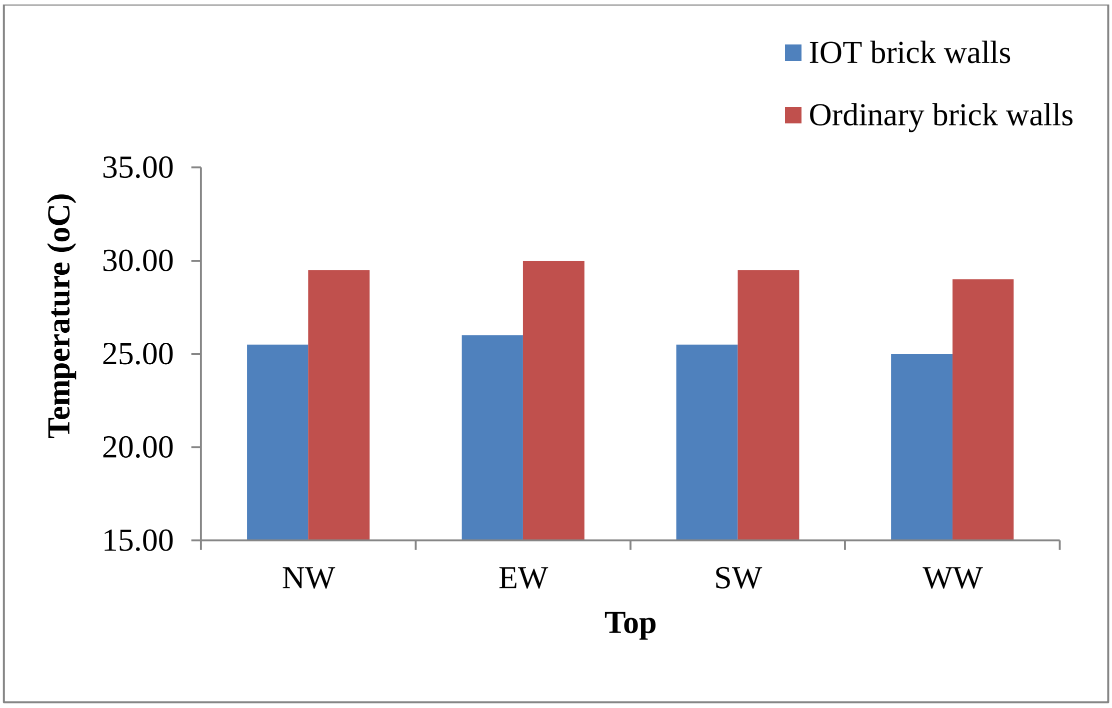

Figure 4.13 Temperature measured in IOTs – Perlite bricks and ordinary bricks of the outside walls at 1 foot below the roof from 8am to 10am

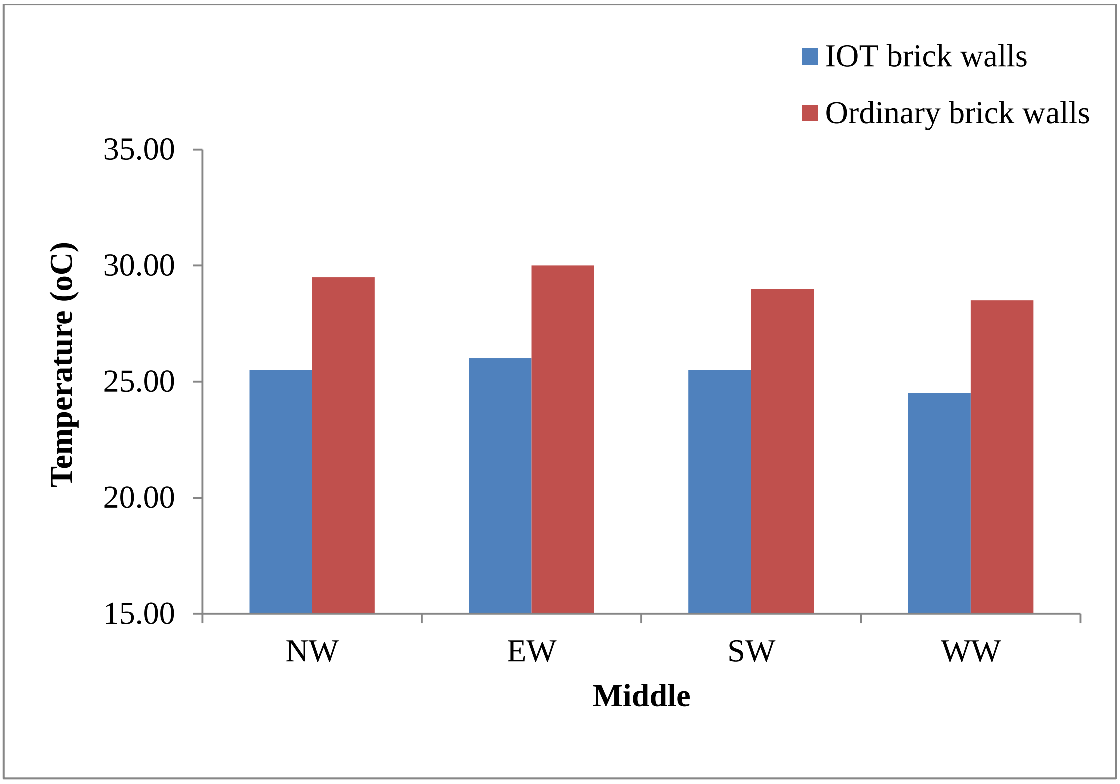

Figure 4.14 Temperature measured from 8am to 10am at middle of the outside walls

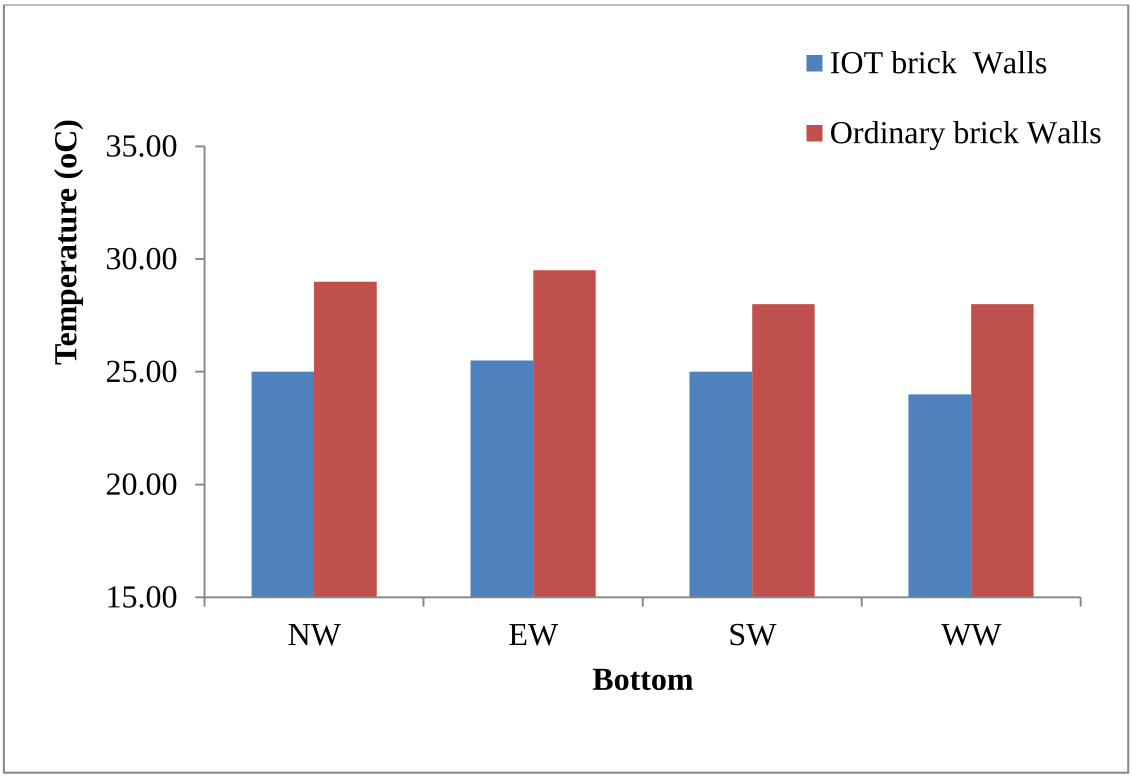

Figure 4.15 Temperature measured at 1 foot above the floor of outside walls from 8am to 10am

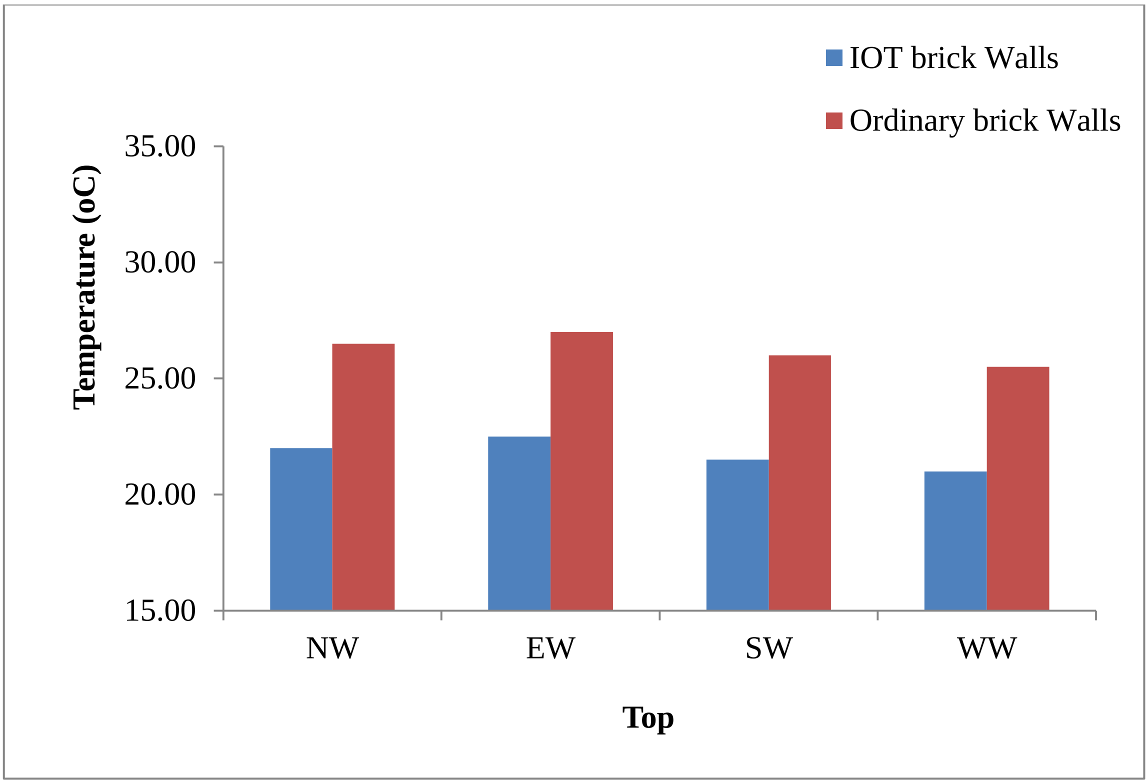

Figure 4.16 Temperature of the inside walls measured at 1 foot below the roof from 8am to 10am

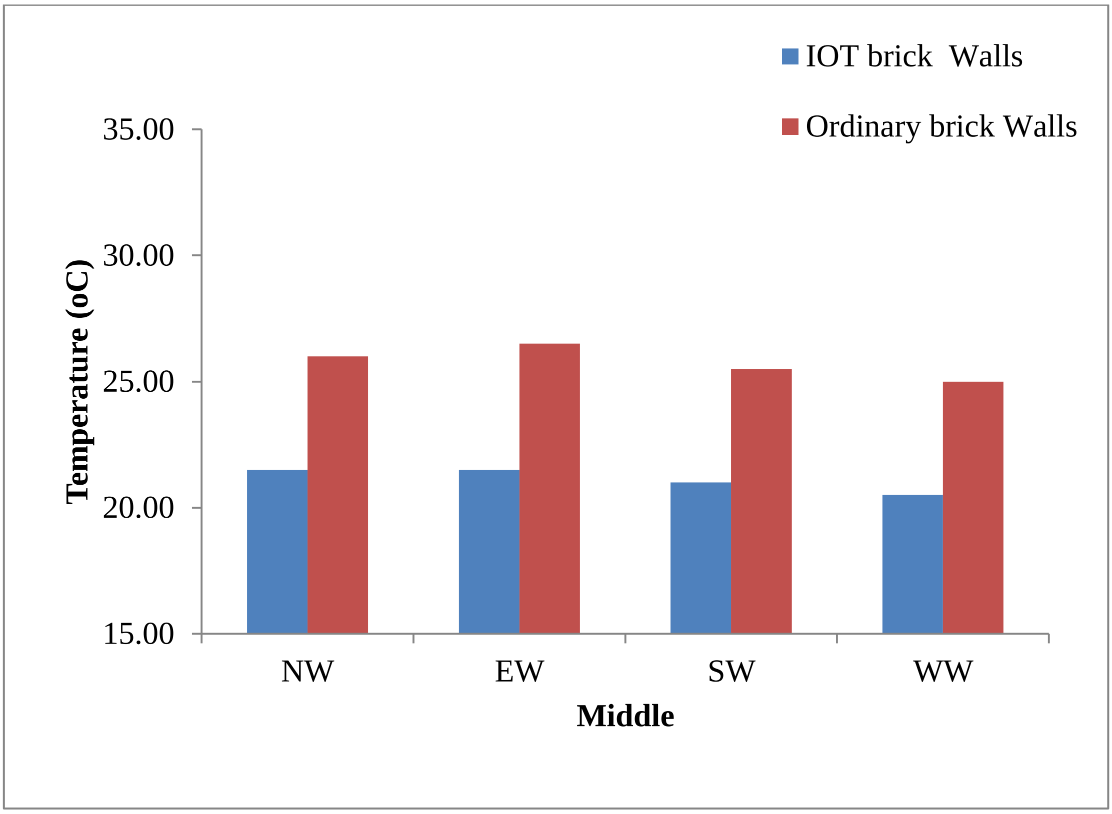

Figure 4.17 Temperature measured from 8am to 10am at middle of the inside walls

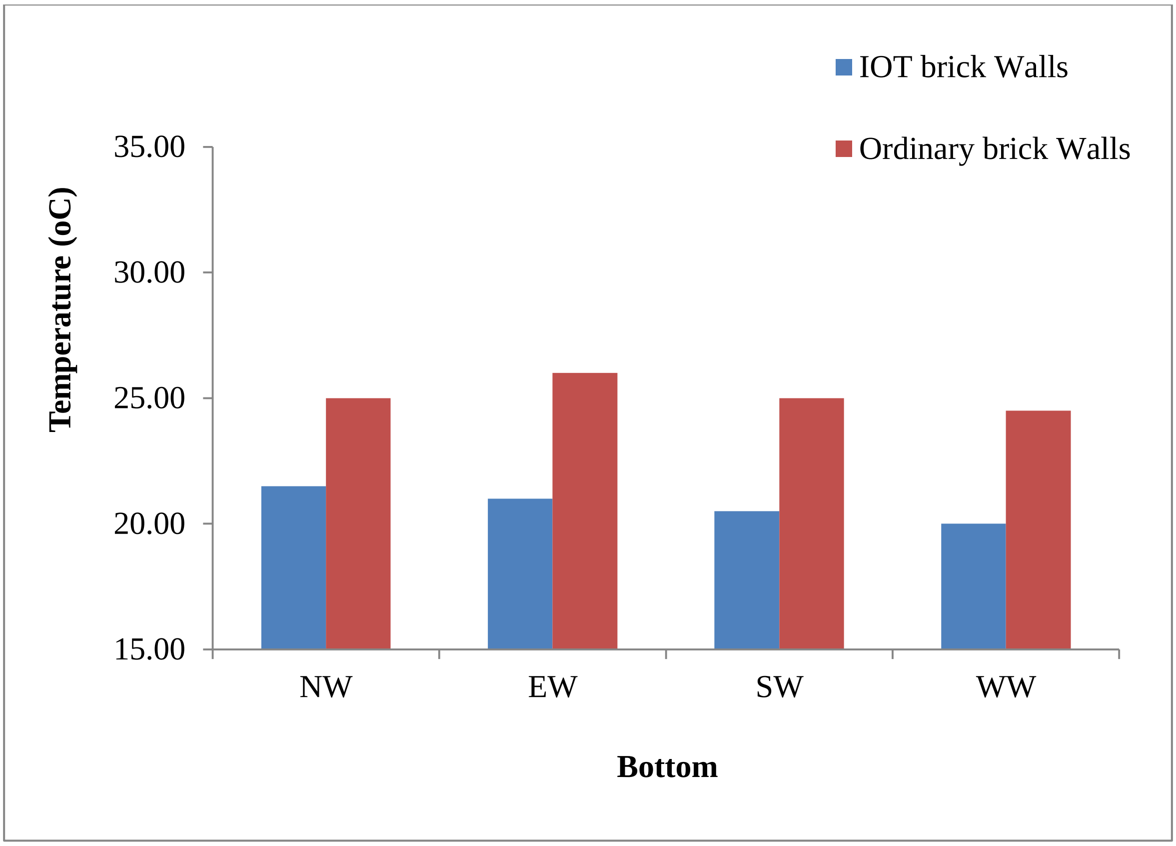

Figure 4.18 Temperature measured from 8am to 10am at 1 foot above the floor of inside walls

4.2.1.2 Measurement of temperature in the afternoon from 12pm to 3pm

The temperature readings taken on inside and outside walls of IOTs – Perlite bricks and ordinary bricks walls during 12pm to 3pm plotted to know the difference in temperature occurred. Figure 4.19 indicates the comparison of temperature when it is measured 1 foot below the roof of the outside walls; Figure 4.20 shows the temperature at middle of the walls at outside walls; Temperature variation at 1 foot above the floor represented in Figure 4.21 of the outside walls. The inside walls temperature difference is represented in Figure 4.22, Figure 4.23 and Figure 4.24.

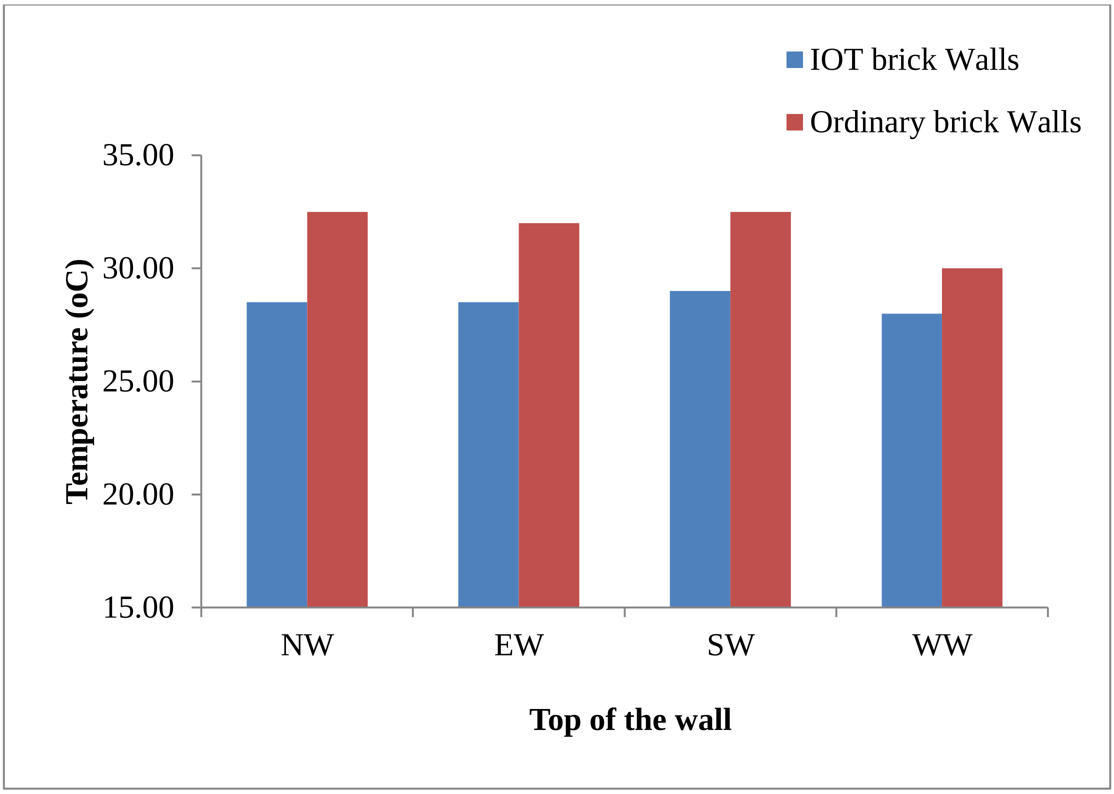

Figure 4.19 Temperature measured from 12pm to 3pm at 1 foot below the roof of the outside walls

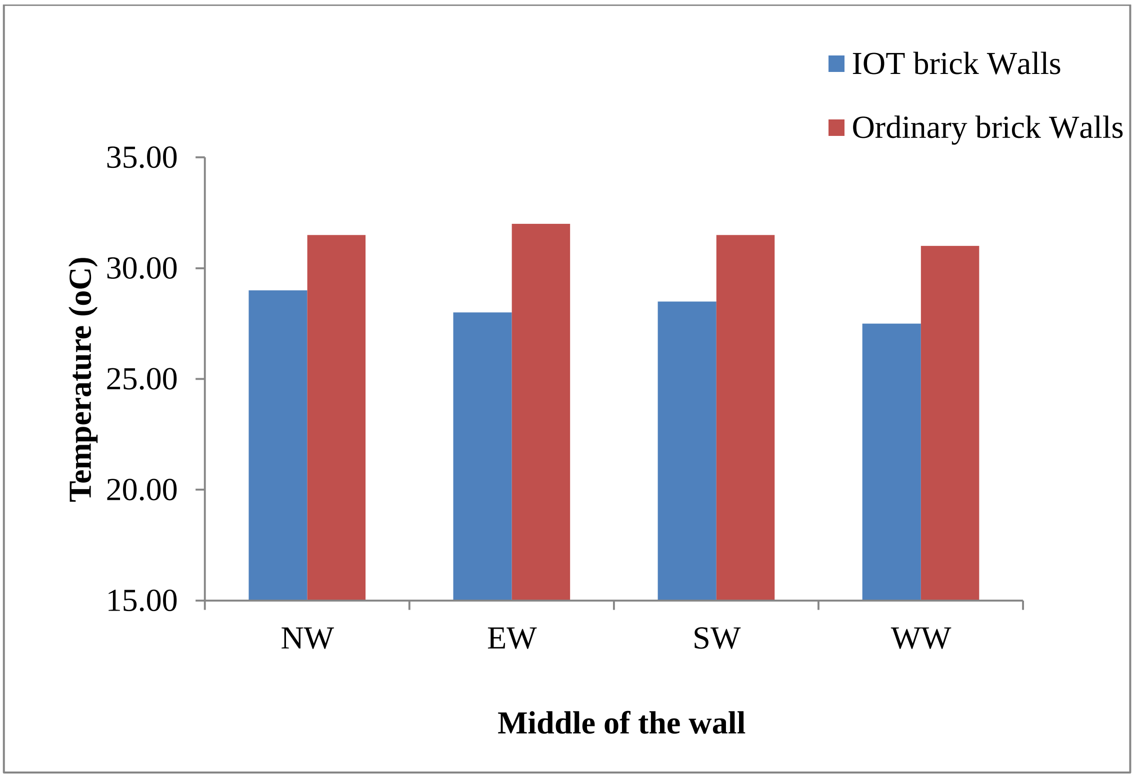

Figure 4.20 Temperature measured from12pm to 3pm at middle of the outside walls

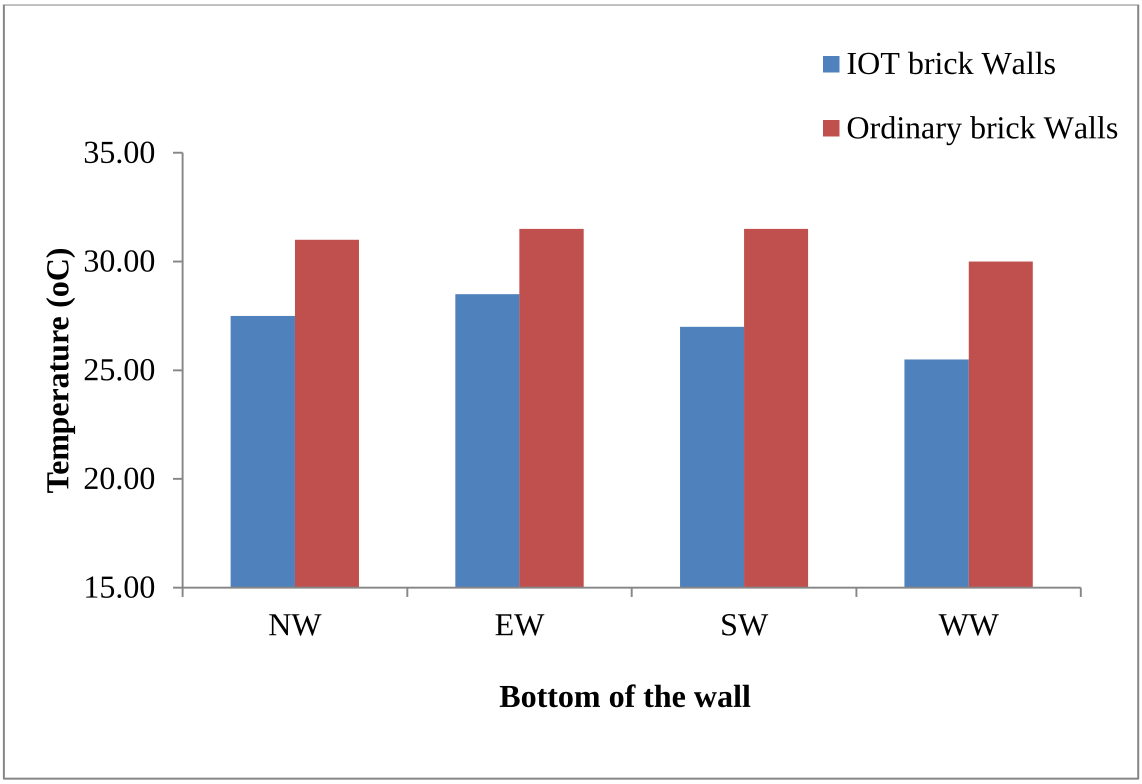

Figure 4.21 Temperature measured from 12pm to 3pm at 1 foot above the floor of the outside walls

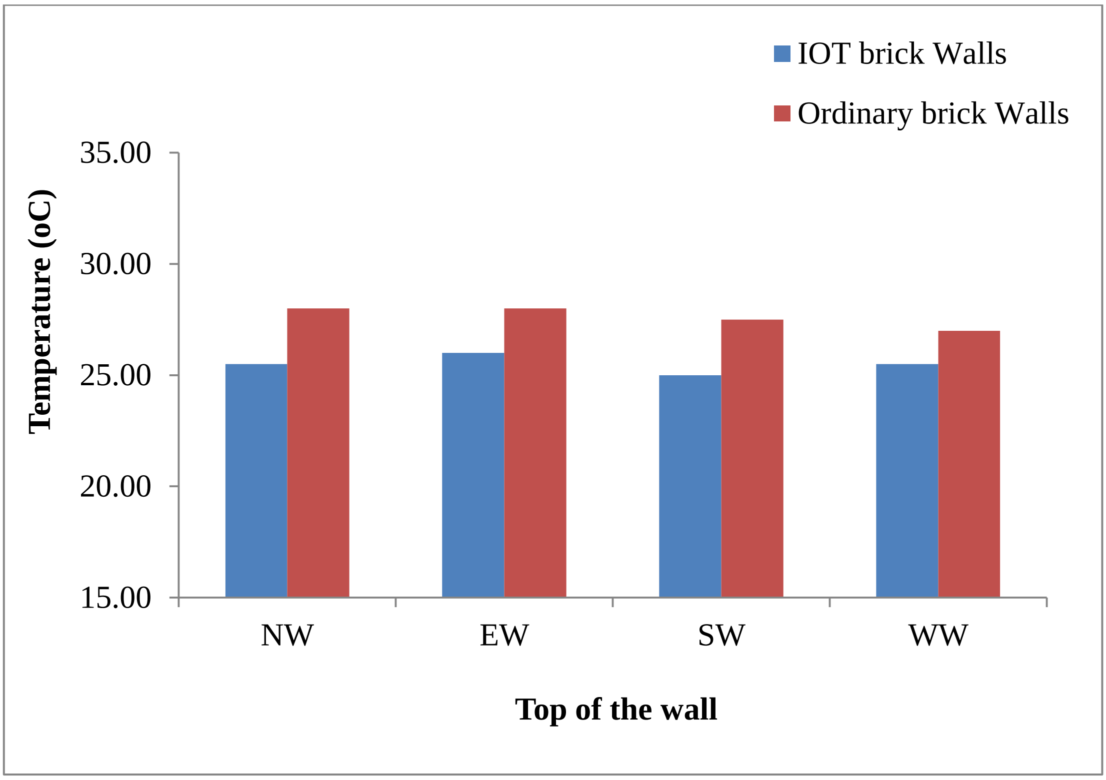

Figure 4.22 Temperature measured from 12pm to 3pm at 1 foot below the roof of the inside walls

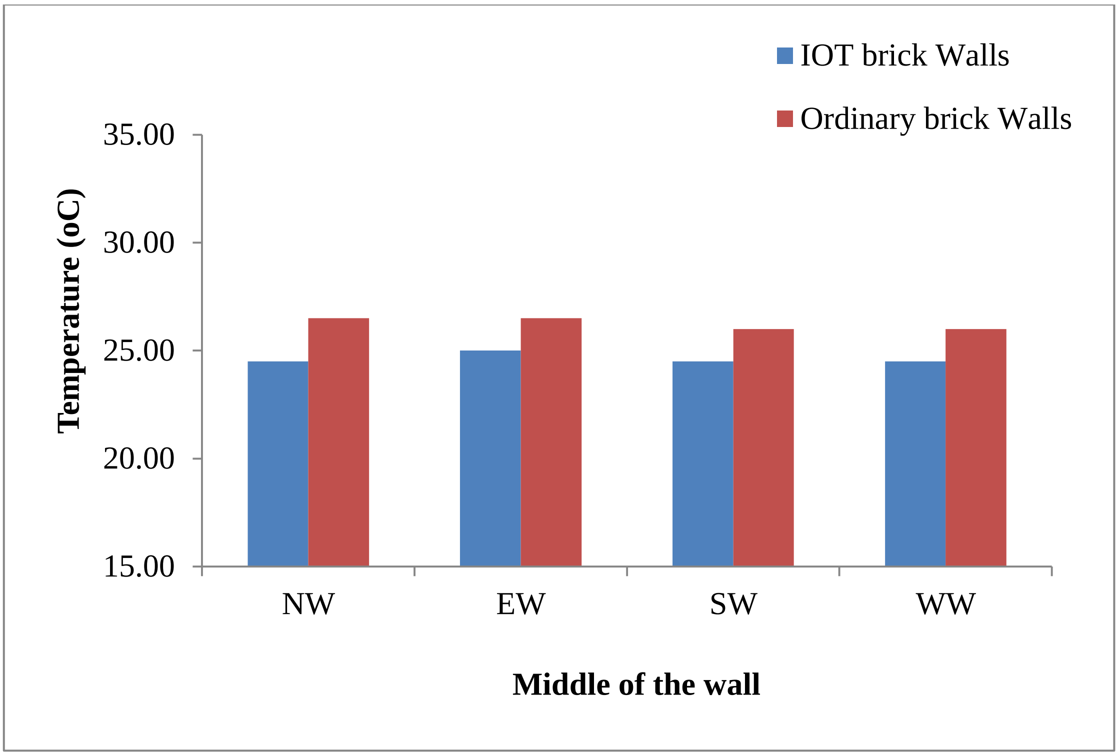

Figure 4.23 Temperature measured from 12pm to 3pm at middle of the inside walls

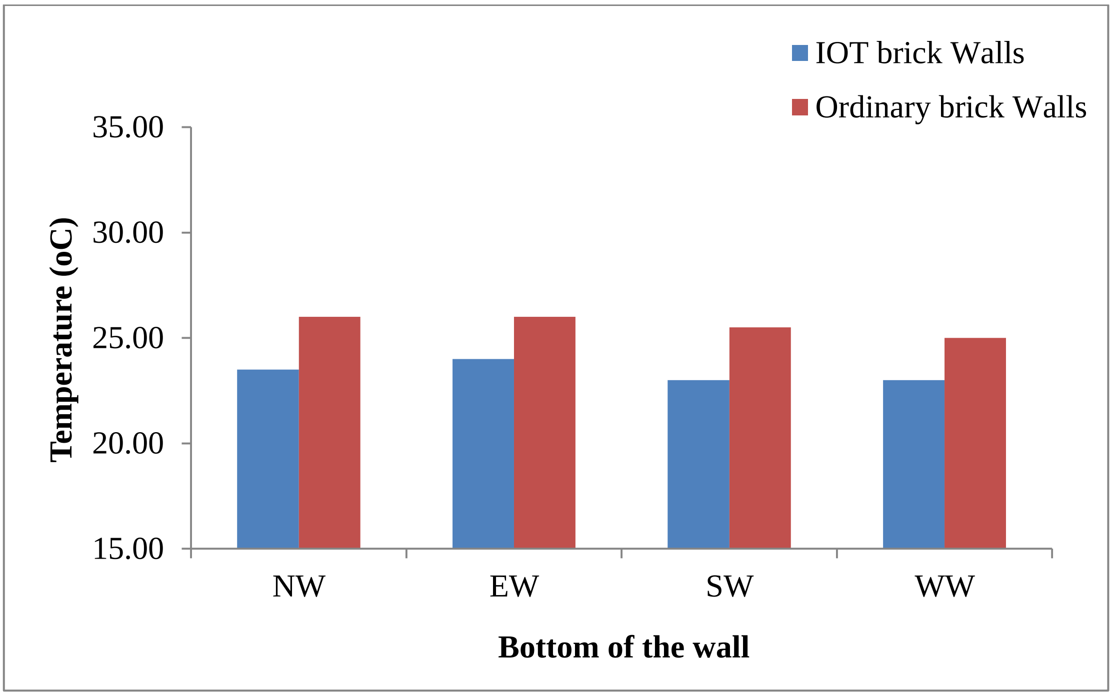

Figure 4.24 Temperature measured from 12pm to 3pm at 1 foot above the floor of the inside walls

The radiation from outside to inside walls is transferred by process of conduction through all directions which are seldom steady. The temperature at midday is higher at the east, north and south walls compared to the west wall. Ambient temperature is arrested by

IOTs - Perlite brick from outside surface is 5%, more when compared to ordinary bricks. The transfer of heat from outside to inside of the ordinary and IOTs – Perlite brick is less by 13% and 14% respectively, ordinary bricks have shown 1% less temperature difference. But, by and large when the temperature of inside surface of the bricks is measured, IOTs – Perlite bricks found slightly less compared to that ordinary bricks. It justifies that lower effect of radiation and conduction of the bricks made of IOT and Perlite. The room temperature of IOTs – Perlite brick room is 5% less than the ordinary brick room. It could be concluded that, in midday, the temperature at walls, floor and room of IOT – perlite bricks are low compared to conventional bricks, because of thermal resistivity of perlite.

4.2.1.3 Measurement of temperature in the evening from 4pm to 6pm

Similar to morning and afternoon, the temperature readings in the evening also taken for side of the brick walls in all directions. It is to know the ambient temperature arrested in IOT – Perlite brick and ordinary brick which are shown in Figure 4.25, Figure 4.26 and Figure 4.27 for 1 foot below roof, at the middle of wall and 1 foot above the ground respectively. The temperature of inner surface of the walls in all directions of both the model rooms are measured and plotted in Figure 4.28, Figure 4.29 and Figure 4.30.

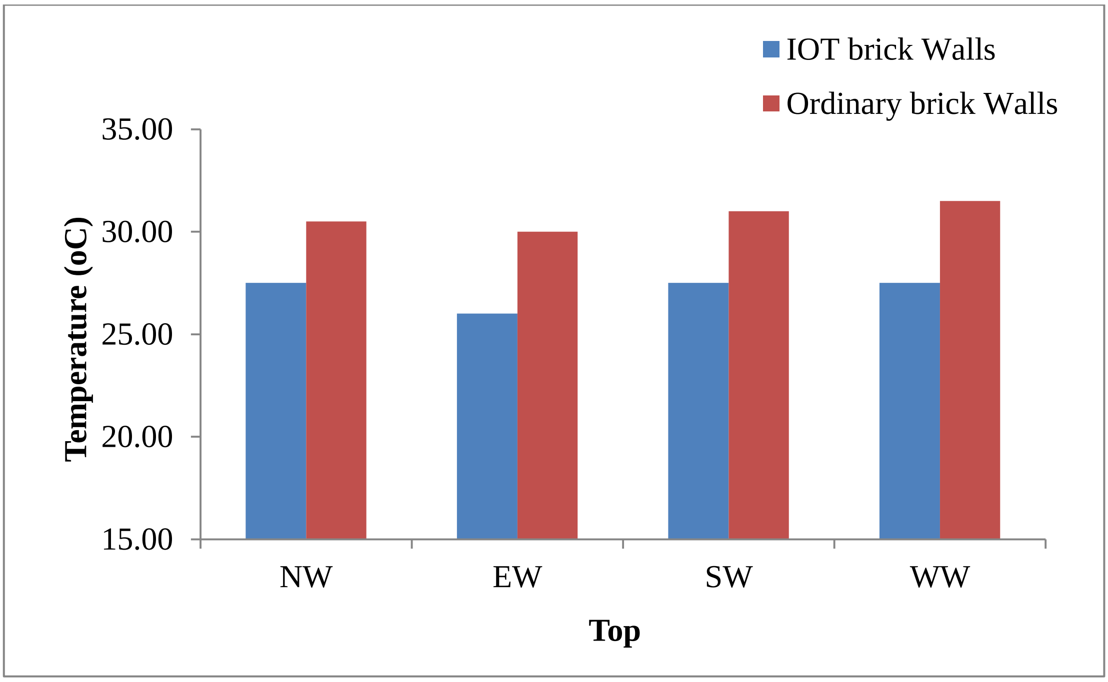

Figure 4.25 Temperature measured from 4pm to 6pm of the outside walls at 1 foot below the roof

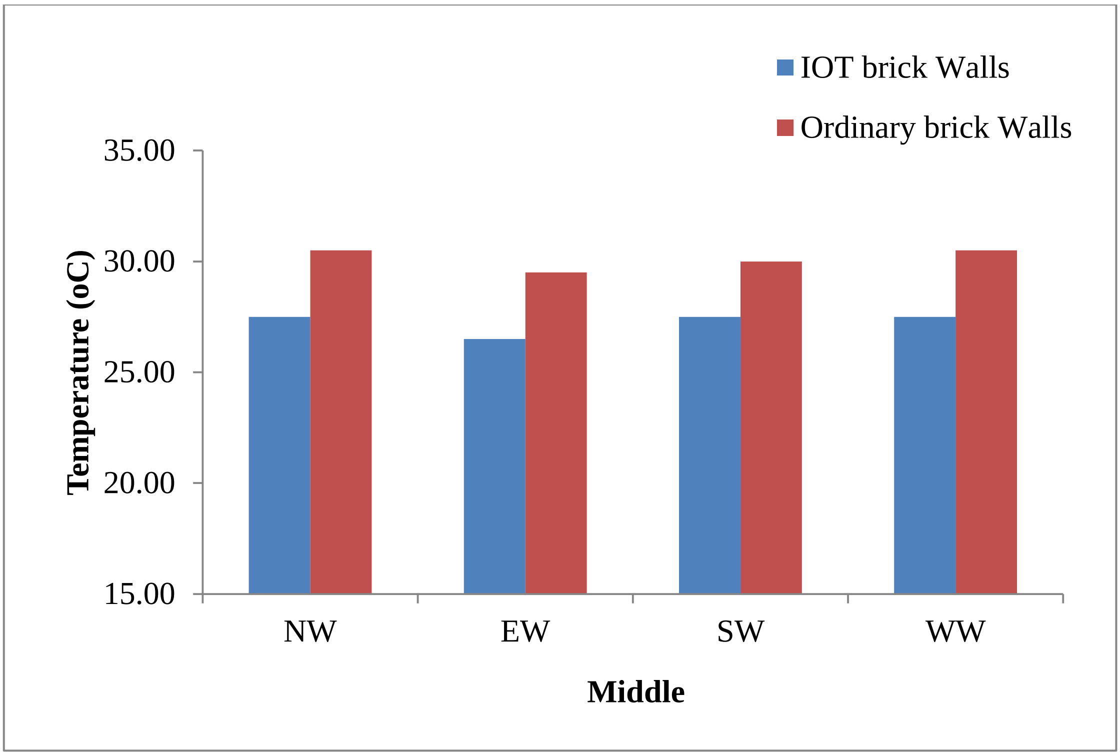

Figure 4.26 Temperature measured from 4pm to 6pm of the outside walls at middle of the wall

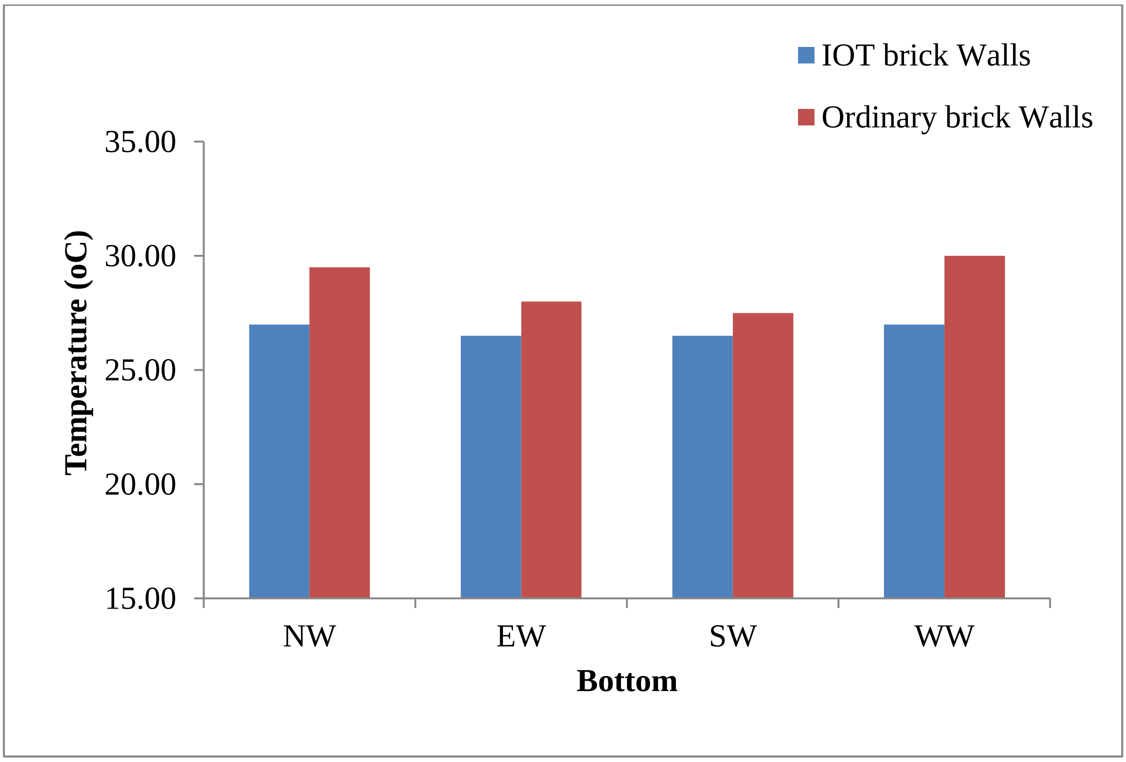

Figure 4.27 Temperature measured from 4pm to 6pm of the outside walls at 1 foot above the floor

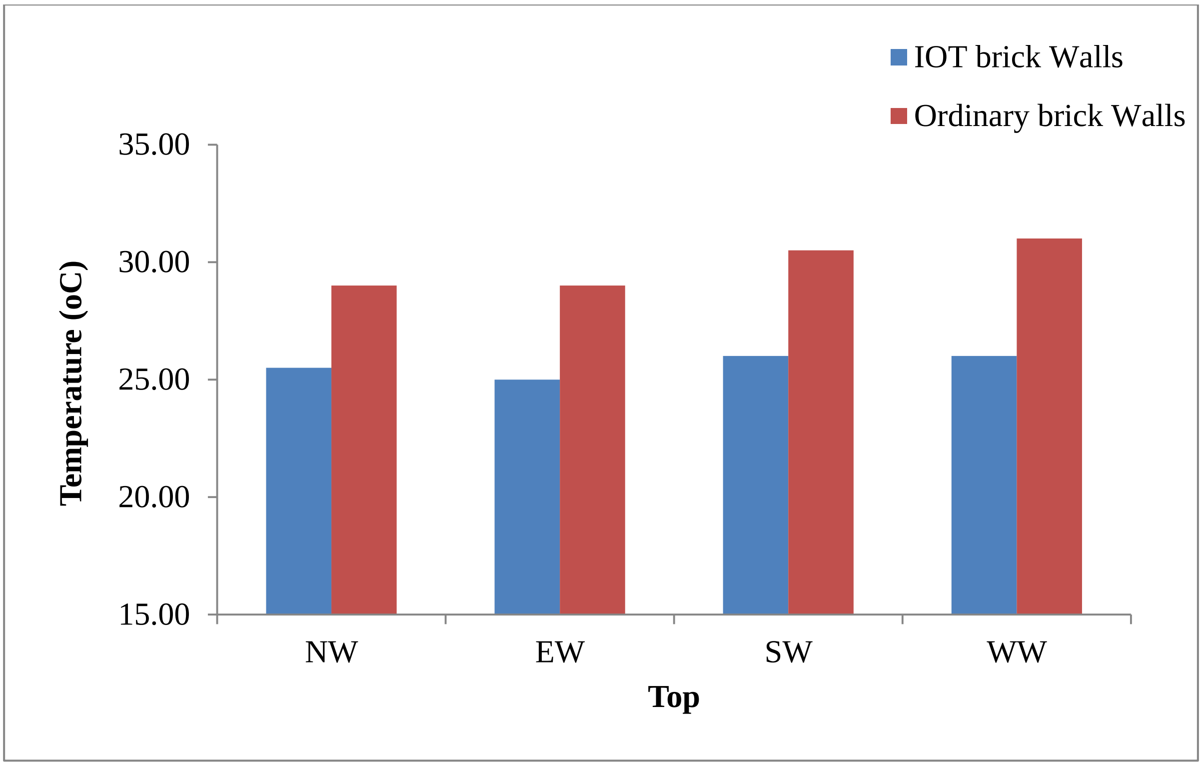

Figure 4.28 Temperature measured from 4pm to 6pm of the inside walls at 1 foot below the roof

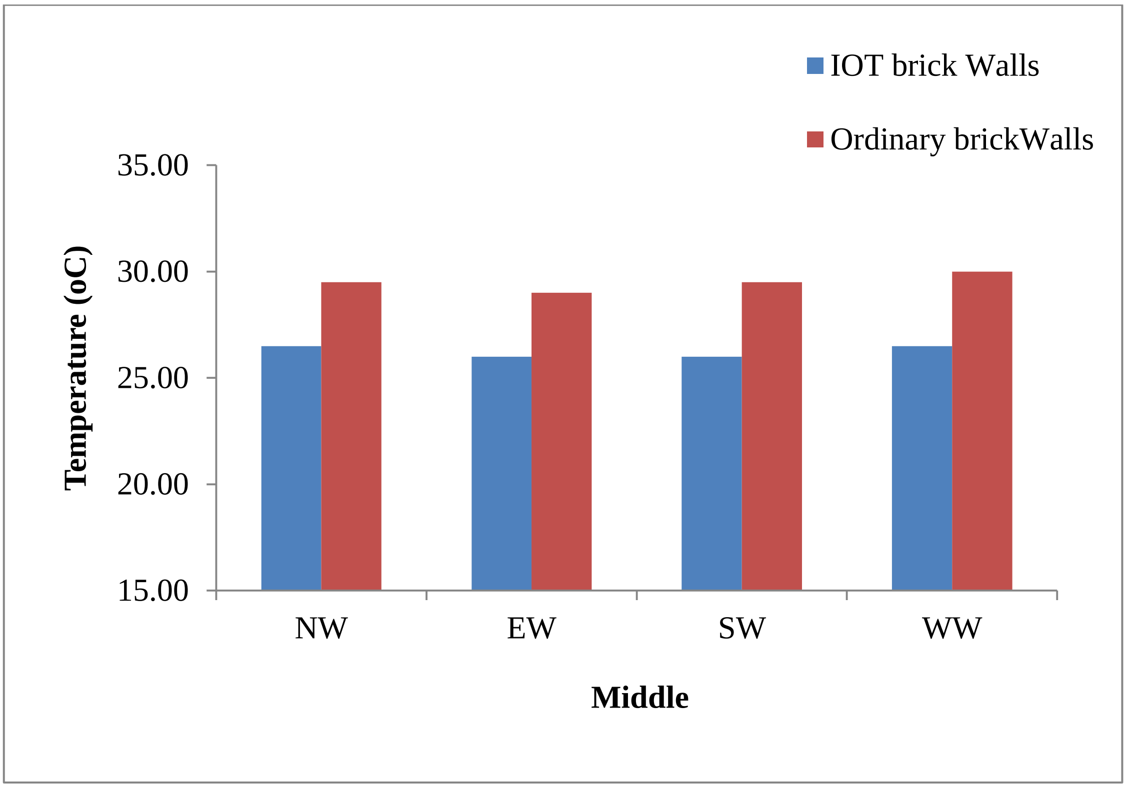

Figure 4.29 Temperature measured from 4pm to 6pm of the inside walls at middle of the wall

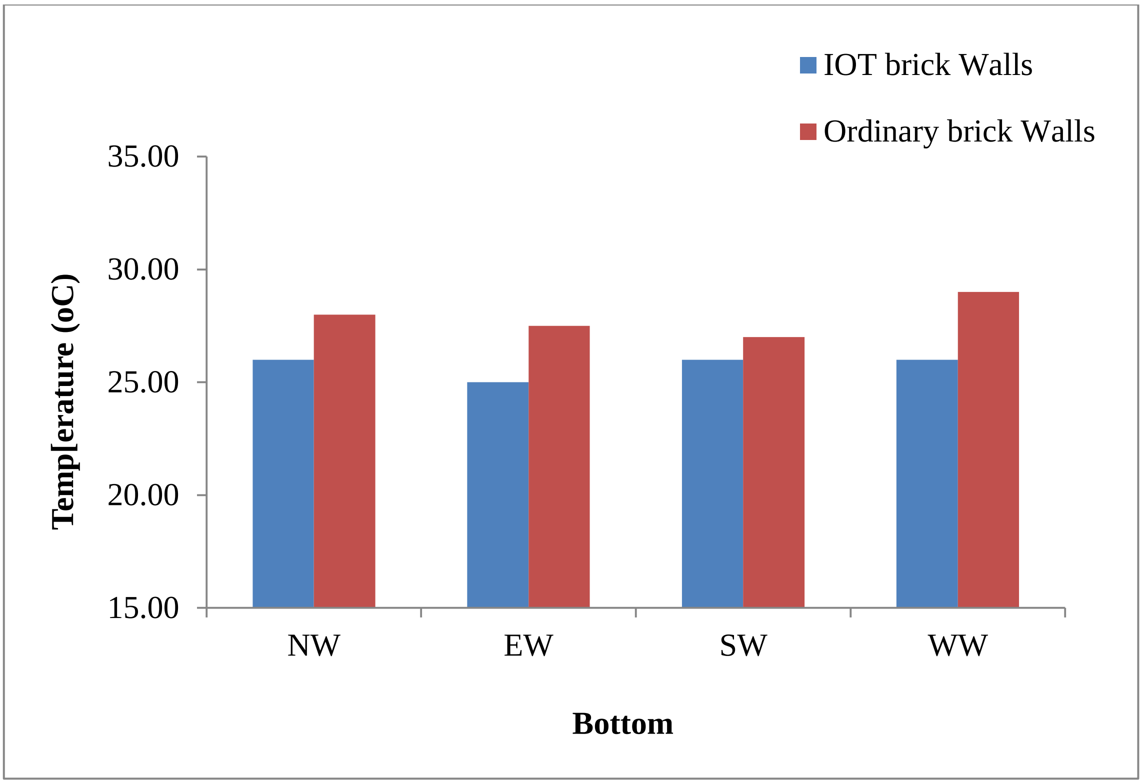

Figure 4.30 Temperature measured from 4pm to 6pm of the inside walls at 1 foot above the floor

The atmospheric temperature in the evening is noted as 28^{o} C. The temperatures in each wall of the rooms (IOT – Perlite bricks and ordinary bricks) are not same and it is varied by atleast 3% to 4%. Temperature of the IOT – Perlite brick walls in outer surface is less by 3% than ambient temperature, which is only 0-1% in the case of ordinary brick walls. The radiation of the sun light is conducted in the IOT – perlite brick walls from outer to inner surface is less by 4%, but in case of ordinary bricks, 2% temperature is lowered. This concludes that the ambient temperature is arrested by outer surface of the IOT – Perlite brick walls by more than 2% and inner surface is atleast 2% less compared to that of ordinary brick walls. The inside room temperature of IOT – Perlite bricks is less by 5% compared to that of ordinary bricks. It is concluded that the temperature is varied in all walls of the four sides, but as an average IOT – Perlite bricks room results in 1 to 2^{0}C less in temperature than ordinary bricks.

In all the above cases, at each location 8 to 10 readings were taken and only average values are reported. The wall of IOTs and Perlite brick room has given the better result in all the cases.

4.2.1.4 Temperature measurement of the room at 5minutes interval before plastering

To confirm the thermal efficiency of model room made of bricks with mine waste such as iron ore tailings and perlite, the room temperature is checked for longer duration. The temperature variation in IOT-Perlite brick room and ordinary brick room are measured at a regular interval of 5 minutes for 55 minutes. It is noticed that the room temperature varies with a change in atmospheric temperature but maintain the average difference at all points of time. It is established that the temperature of the IOT – Perlite brick room is less by 1 - 2^{o}C compared to an ordinary brick room (Figure 4.31). This helps to prove the radiation, conduction and convection of heat through IOT-Perlite brick is less compared to ordinary brick room, by maintaining difference in temperature proportionately throughout with the variation in ambient temperature.

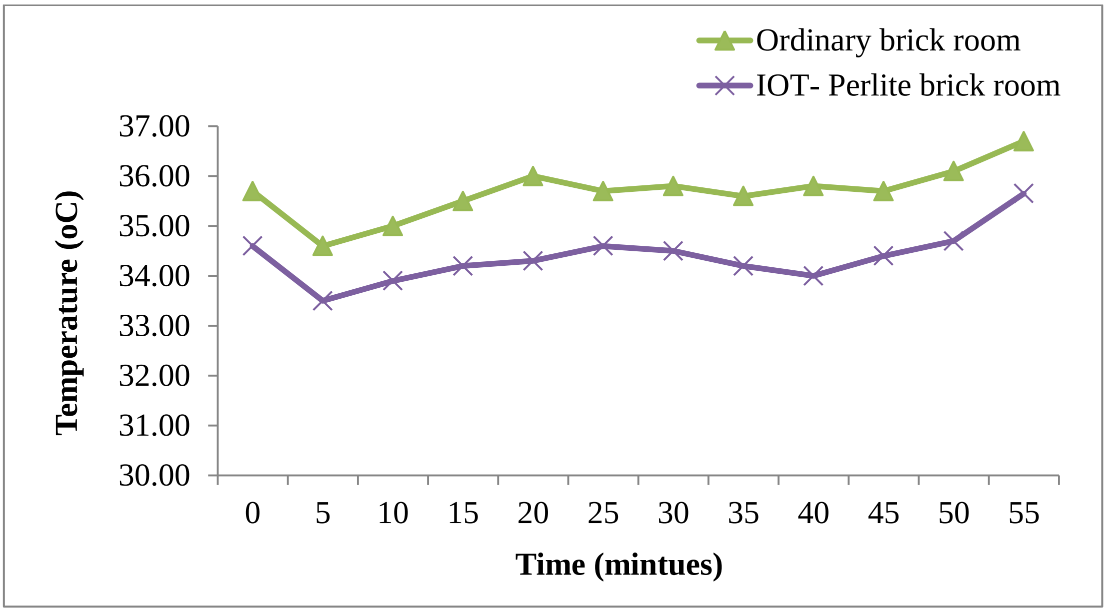

Figure 4.31 Temperature vs time before plastering of model rooms

4.2.2 Thermal efficiency of IOT-perlite bricks vs conventional bricks based on the temperature measurement after plastering

The temperatures of model rooms are measured after plastering. The measurement is taken from 8am to 10am, 12pm to 3pm and 4pm to 6pm.

4.2.2.1 Measurement of temperature in the morning from 8am to 10am

The temperature of ordinary brick room as well as the IOTs and perlite brick room is affected by ambient temperature and solar radiation. In peak condition also temperature of IOTs and perlite brick room is less than ordinary brick room and ambient temperature. This decrease in wall and room temperature caused in IOTs and perlite brick room is due to addition of perlite in brick, where perlite acts as good thermal resistant material. The perlite arrests the ambient temperature and solar radiation from outside and releases the less heat into the room, which helps to keep the room cool. The comparison of IOT-Perlite brick wall and ordinary brick wall temperature is expressed in graphical representation as shown in the Figure 4.32, Figure 4.33 and Figure 4.34 for outside walls and Figure 4.35, Figure 4.36 and Figure 4.37 for inside walls.

When the ambient temperature was 30^{o}C, the result concludes the after wall plastering the temperature of the IOT- Perlite brick walls in outer surface reduced by 12% than ambient, but in ordinary brick walls temperature arrested 2% less compared to IOT- Perlite brick walls. This difference is compared to without plastering IOT- perlite walls and observed 2% further reduction after plastering of IOT- perlite walls. The room temperature of IOT-perlite brick is less by 8% compared to ordinary brick. When it is compared with without plastering 1% further reduction was obtained. Therefore it gives the better result after plastering of IOTs and Perlite bricks room and also can save the energy consumption in the room because of lower temperature.

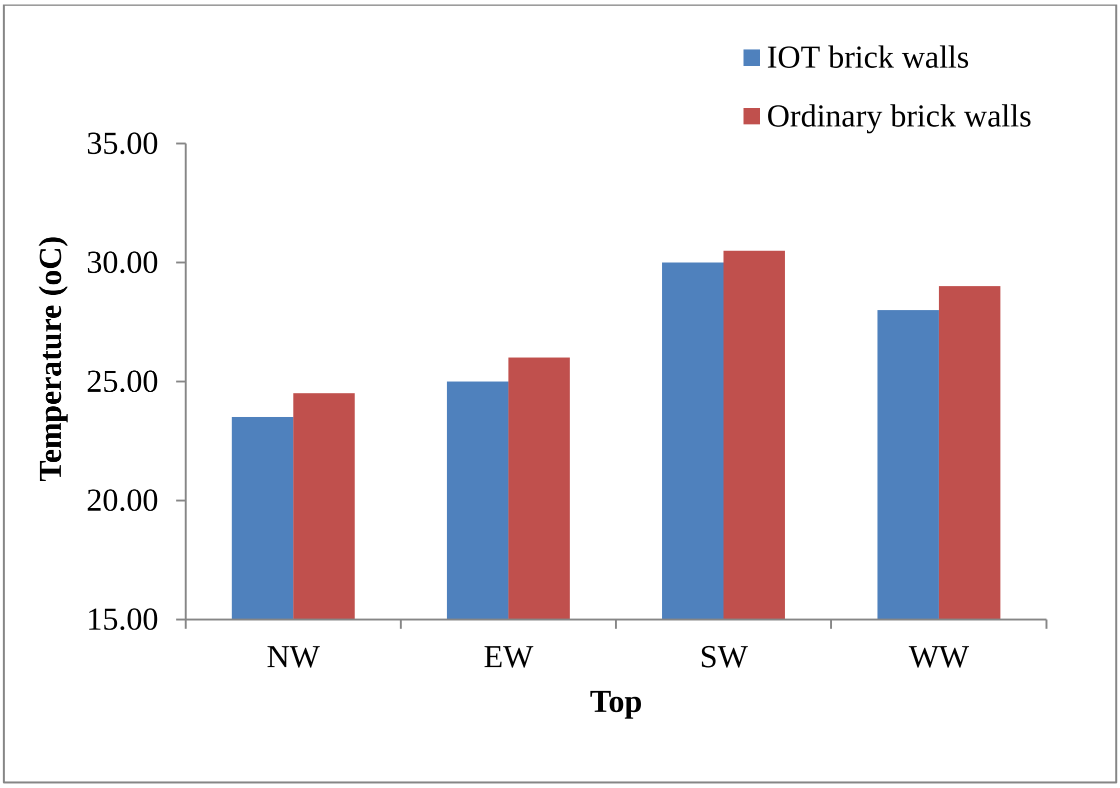

Figure 4.32 Temperature measured from 8am to 10am at top point of the outside walls

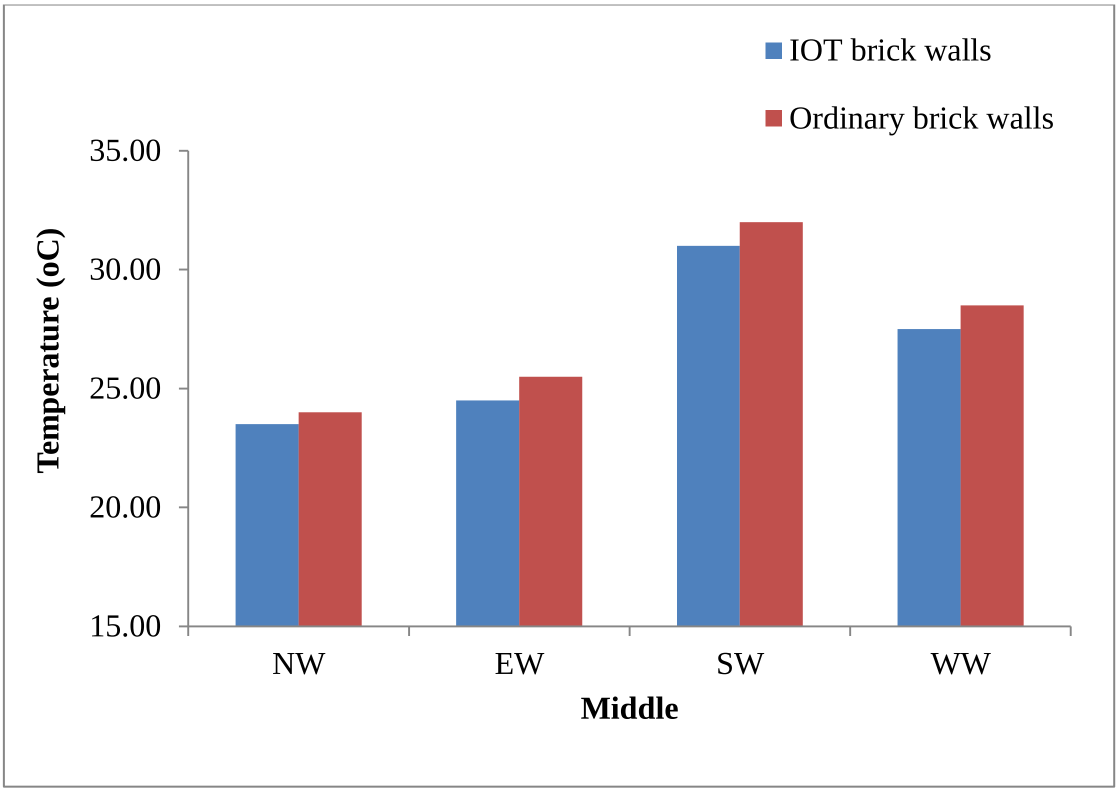

Figure 4.33 Temperature measured from 8am to 10am at middle point of the outside walls

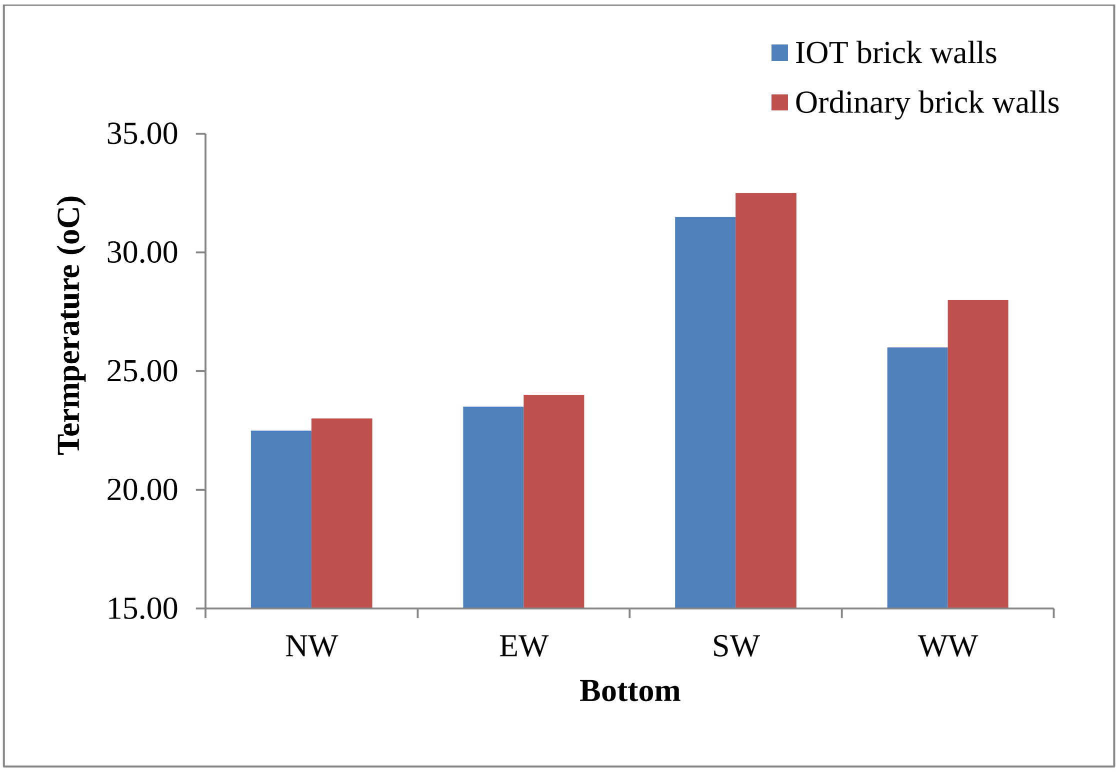

Figure 4.34 Temperature measured from 8am to 10am at bottom point of the outside walls

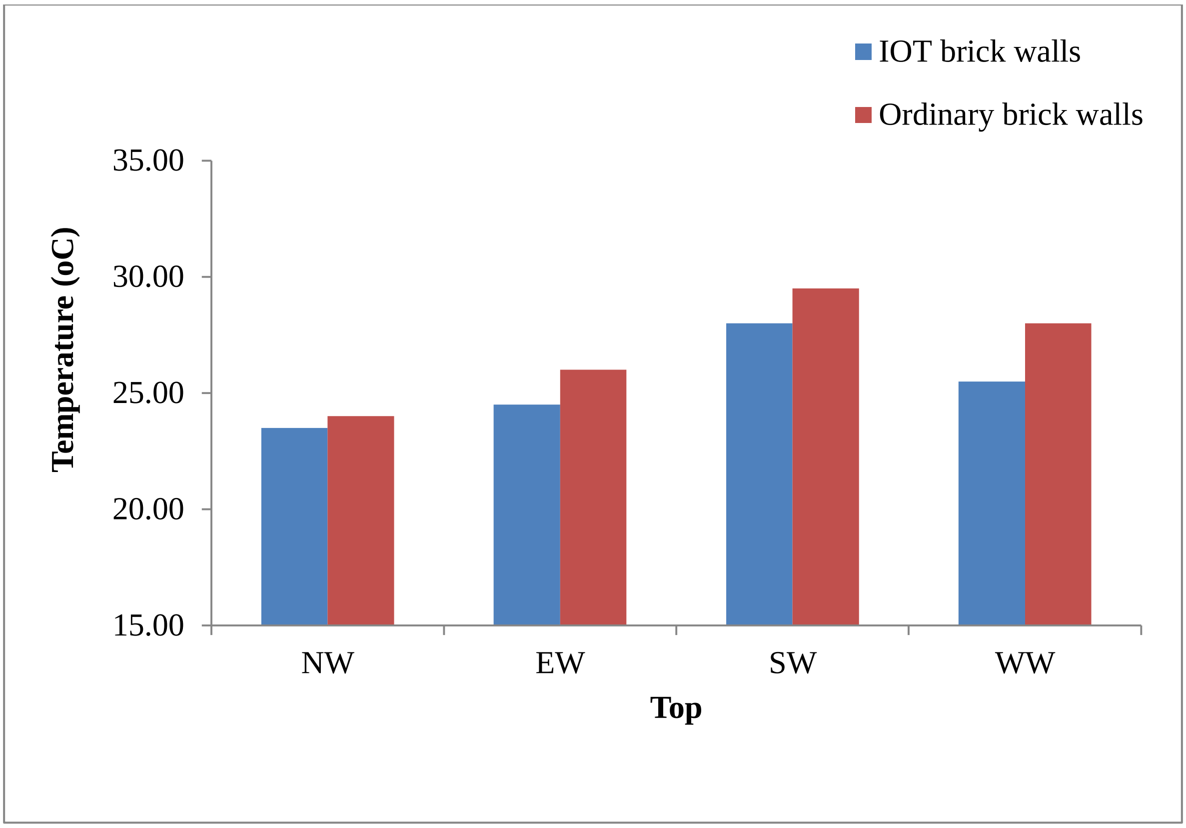

Figure 4.35 Temperature measured from 8am to 10am at top point of the inside walls

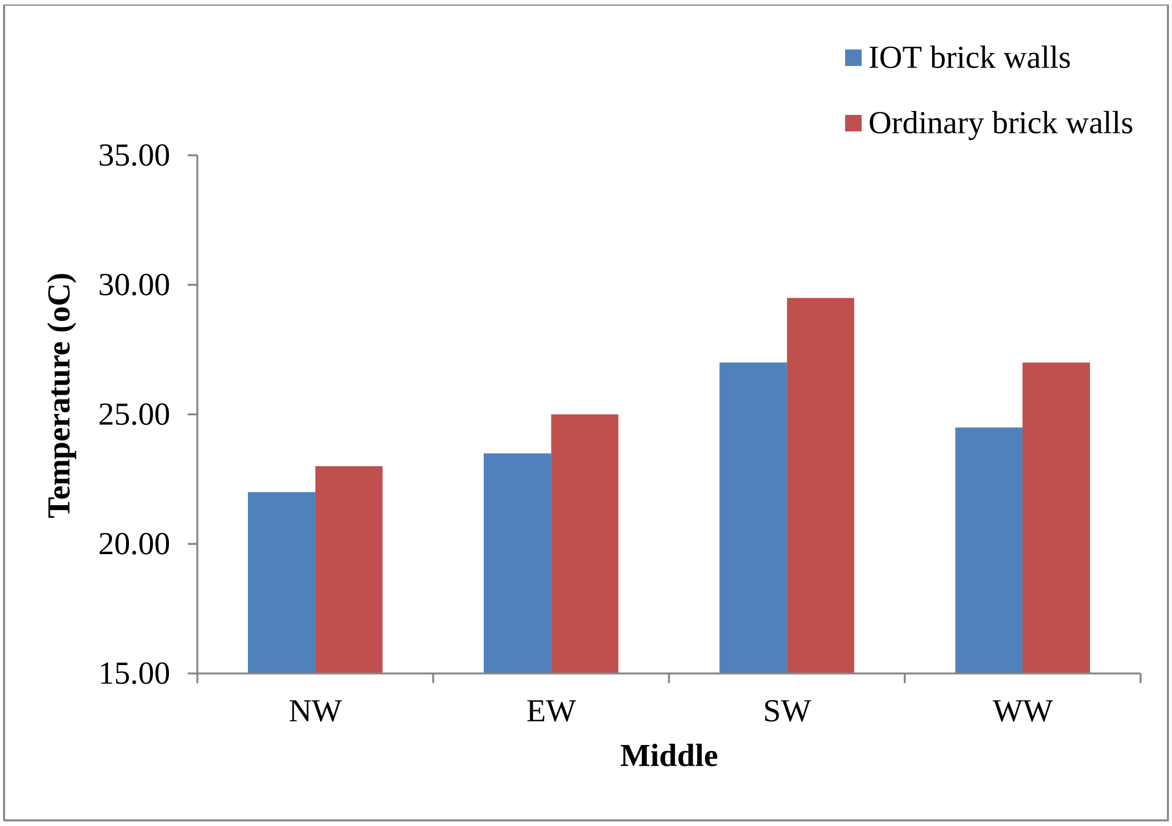

Figure 4.36 Temperature measured from 8am to 10am at middle point of the inside walls

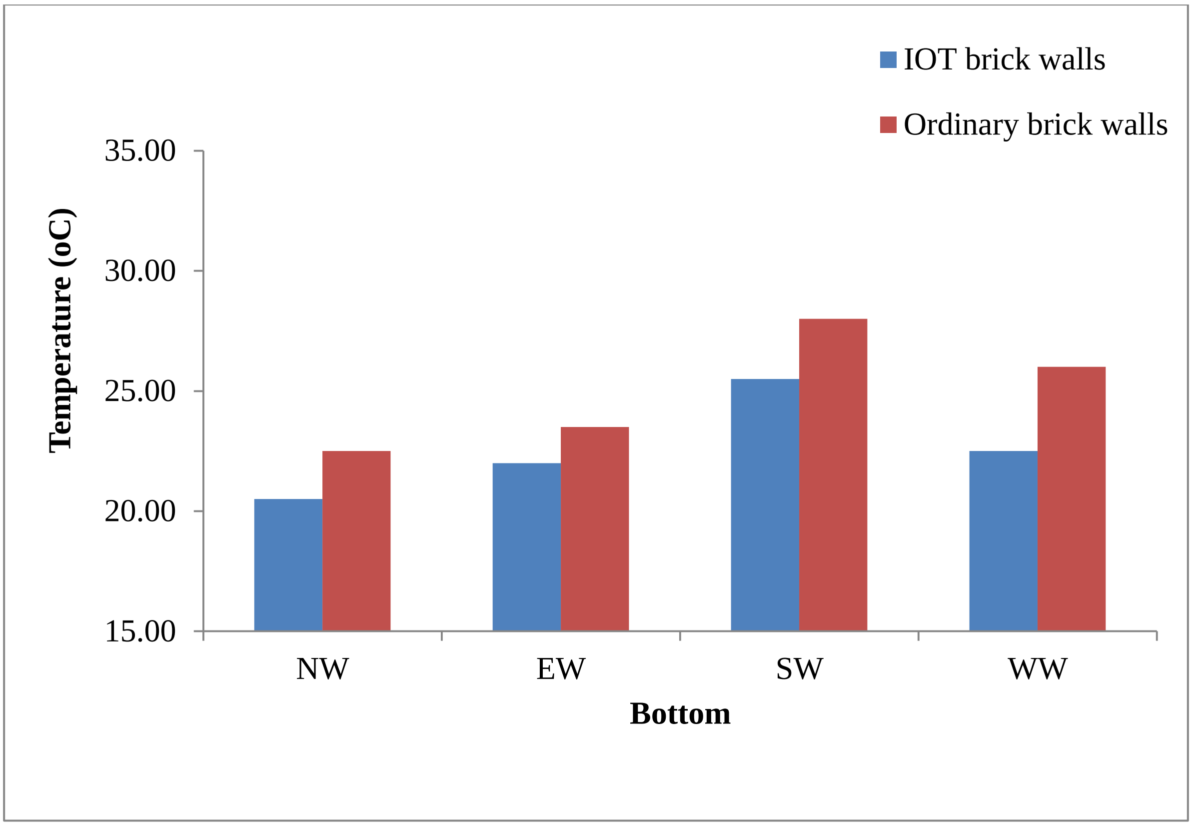

Figure 4.37 Temperature measured from 8am to 10am at bottom point of the inside walls

4.2.2.2 Measurement of temperature in the afternoon from 12pm to 3pm

The temperature readings taken on inside and outside walls after plastering of IOT-perlite bricks and ordinary bricks during 12pm to 3pm is shown in Figure 4.38, Figure 4.39 and Figure 4.40 for outside walls and Figure 4.41, Figure 4.42 and Figure 4.43 for inside walls.

The atmospheric temperature is 34.50^{o}C between 12pm and 3pm. Ambient temperature is arrested by IOT – Perlite brick from outer surface is 6%, more than ordinary bricks and 1% more than non-plastered IOT- Perlite brick wall. The transfer of heat from outside to inside of the ordinary and IOT – Perlite brick is less by 5% and 7% respectively, ordinary brick have shown 2% less temperature difference. The room temperature of IOT-perlite brick is less by 8% compared to ordinary brick. When it is compared with without plastering 1% further reduction was observed.

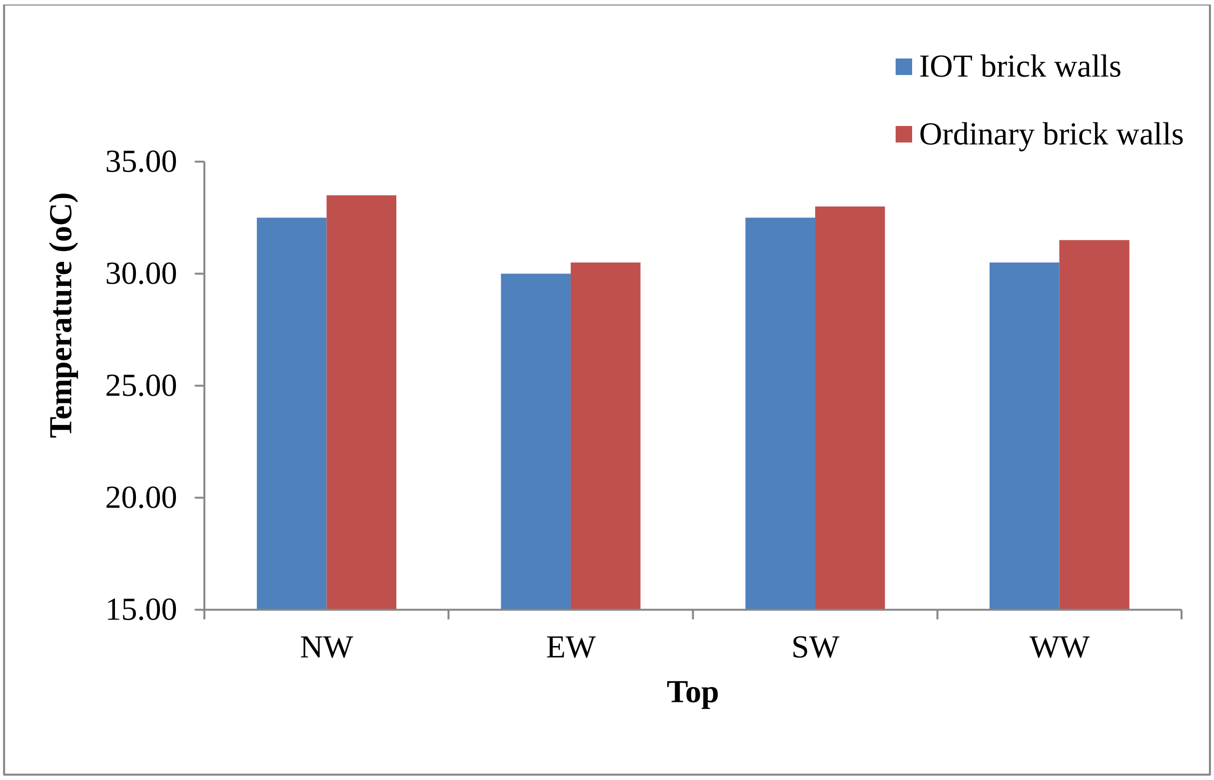

Figure 4.38 Temperature measured from 12pm to 3pm at top point of the outside walls

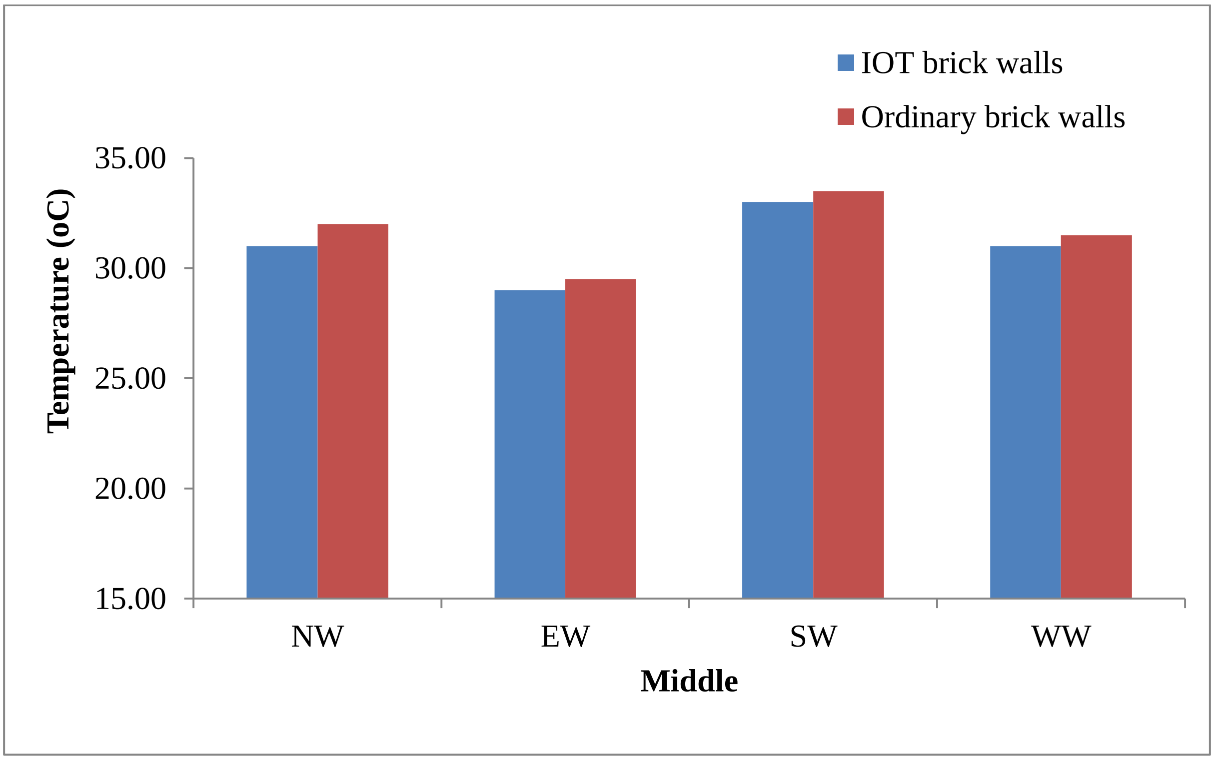

Figure 4.39 Temperature measured from 12pm to 3pm at middle point of the outside walls

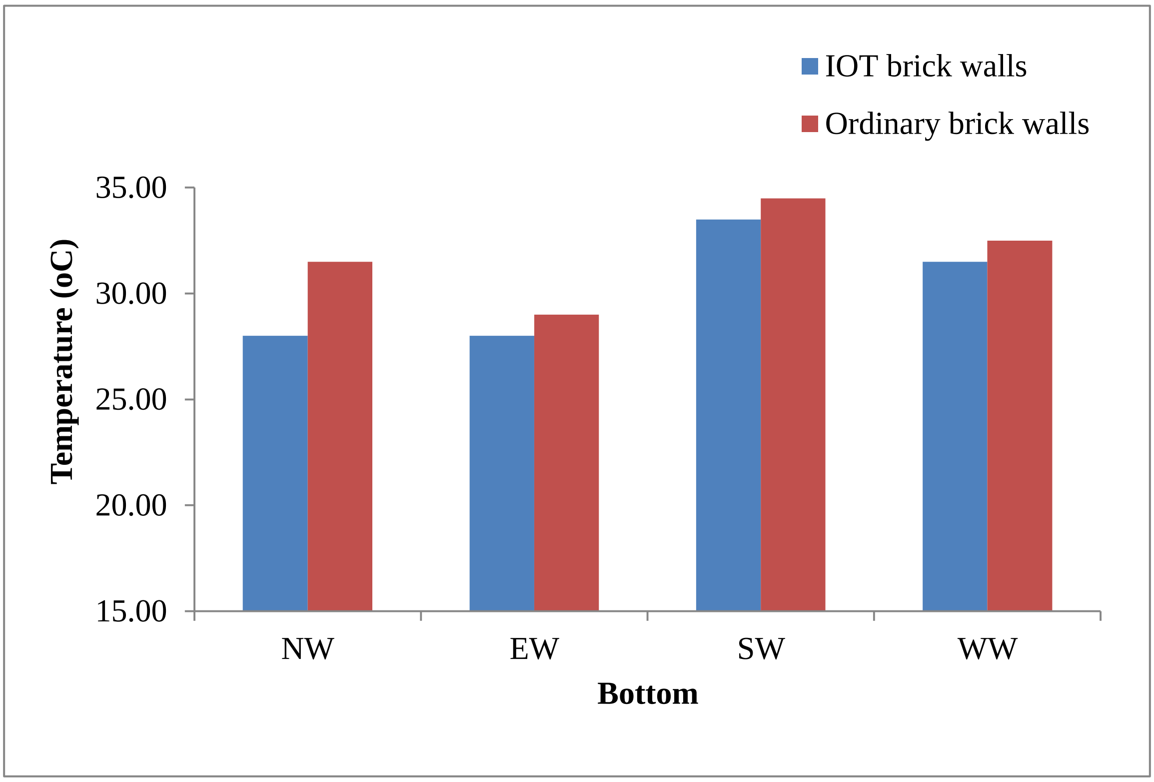

Figure 4.40 Temperature measured from 12pm to 3pm at bottom point of the outside walls

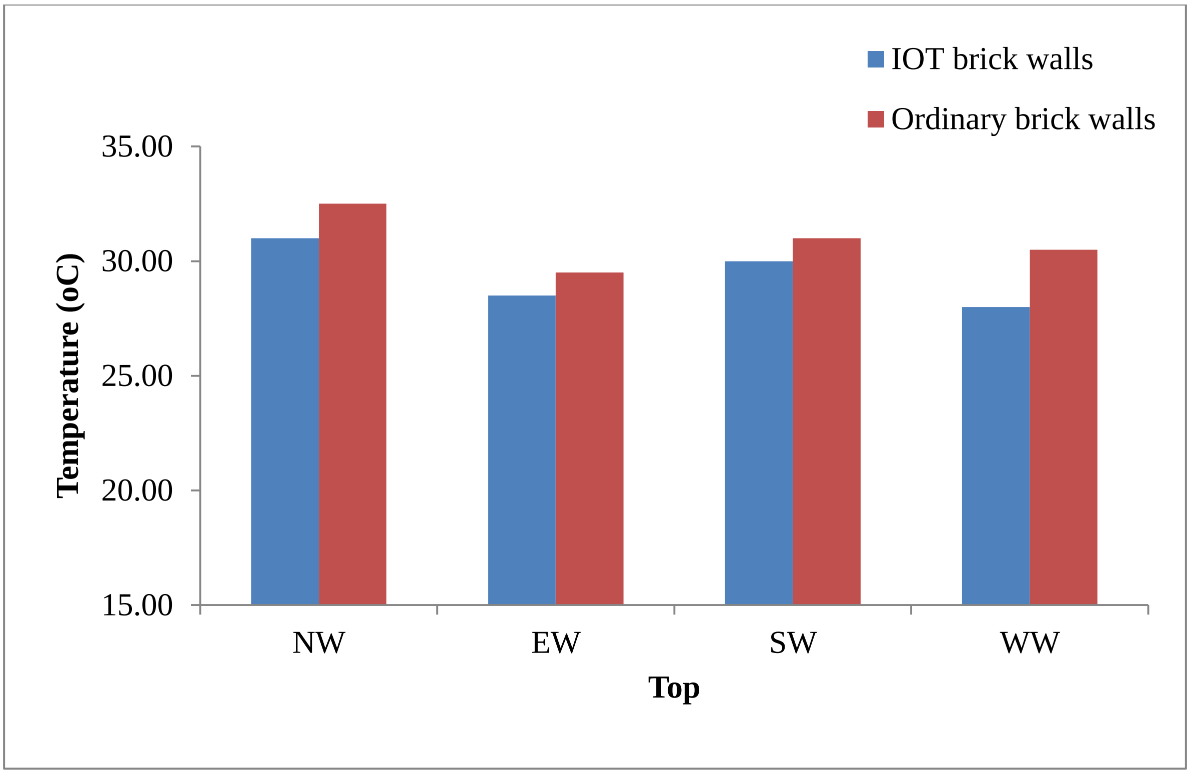

Figure 4.41 Temperature measured from 12pm to 3pm at top point of the inside walls

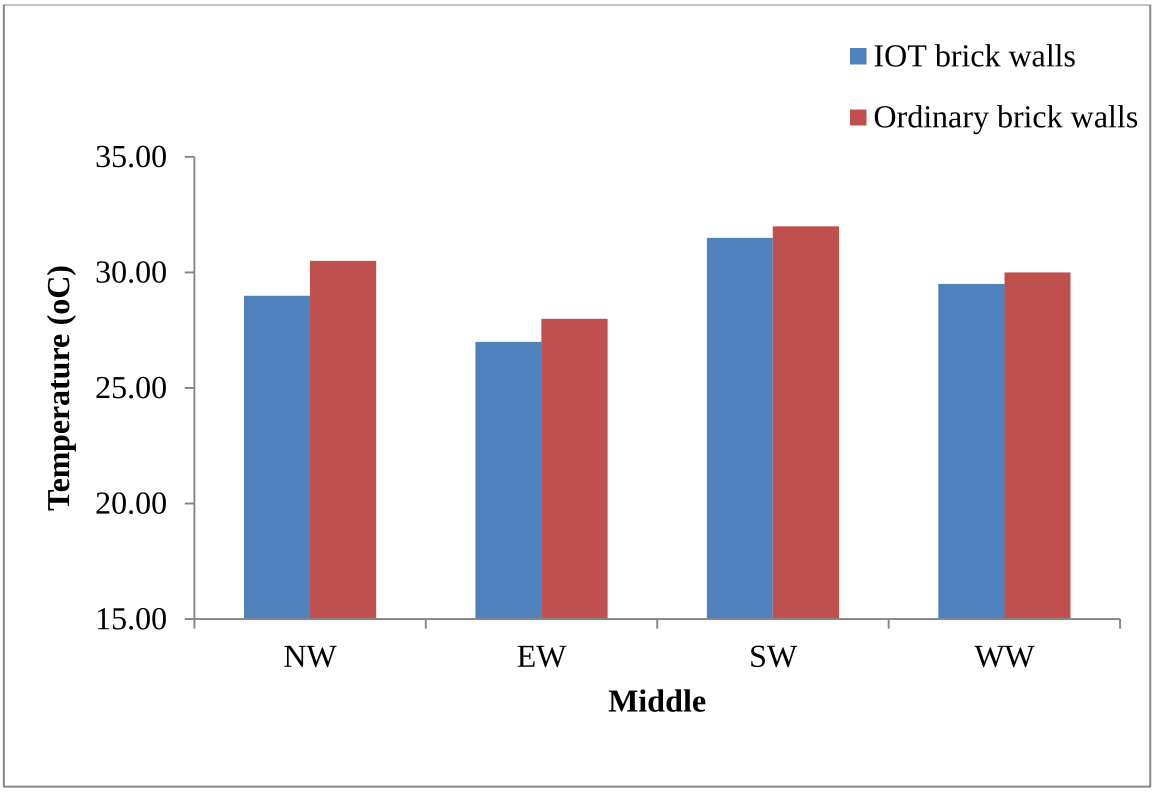

Figure 4.42 Temperature measured from 12pm to 3pm at middle point of the inside walls

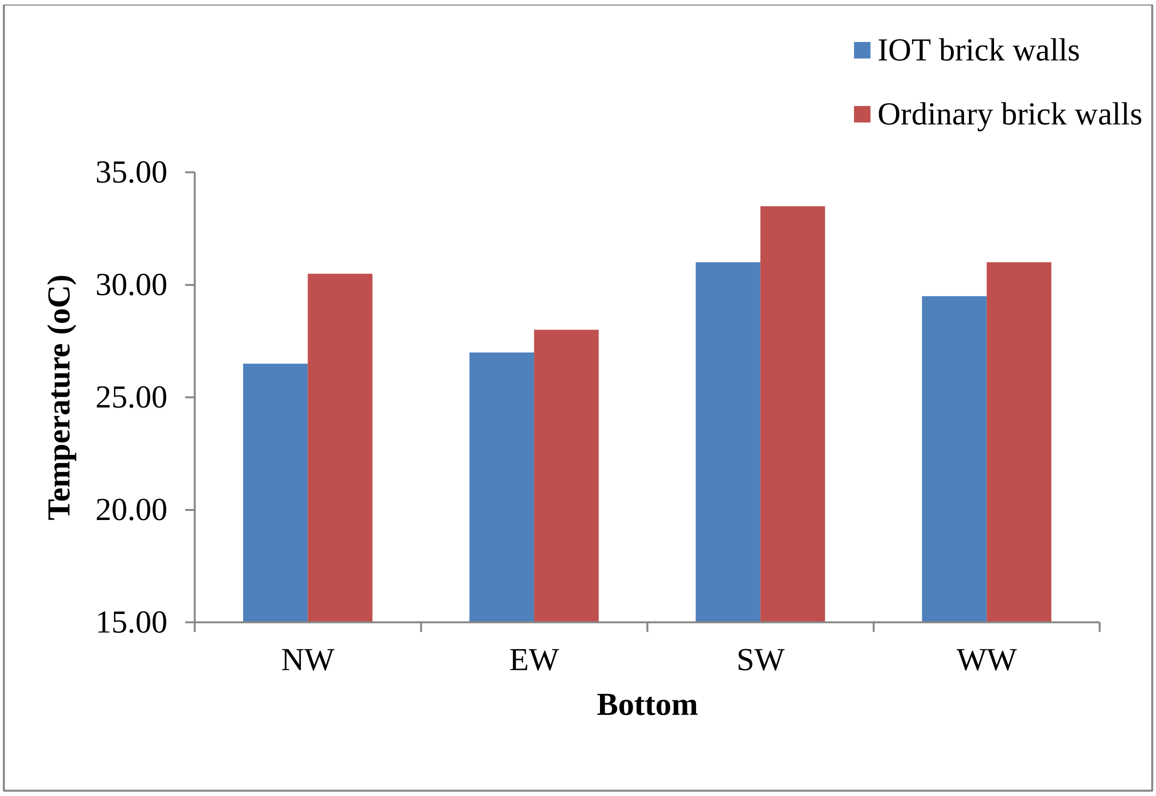

Figure 4.43 Temperature measured from 12pm to 3pm at bottom point of the inside walls

4.2.2.3 Measurement of temperature in the evening from 4pm to 6pm

Similar to morning and afternoon, the temperature readings in the evening is noted. Figure4.44, Figure 4.45 and Figure 4.46 for top, middle and bottom respectively for outside wall of IOT – Perlite brick and ordinary brick temperature is measured. The inside wall temperature of the IOT- Perlite brick and ordinary brick is noted and shown in Figure 4.47, Figure 4.48 and Figure 4.49.

The ambient temperature in the evening was noted as 34.00 ^{o}C. The temperature of IOT – Perlite brick walls in outer surface is less by 14%, it says that the temperature is well arrested at outer wall of the IOT- Perlite brick wall. But in case of ordinary brick wall it arrests about only 8%, hence it proves that IOT – perlite brick walls reduces the temperature. The room temperature of IOT-perlite brick is less by 8% compared to ordinary brick. When it is compared with without plastering 1% further reduction was obtained.

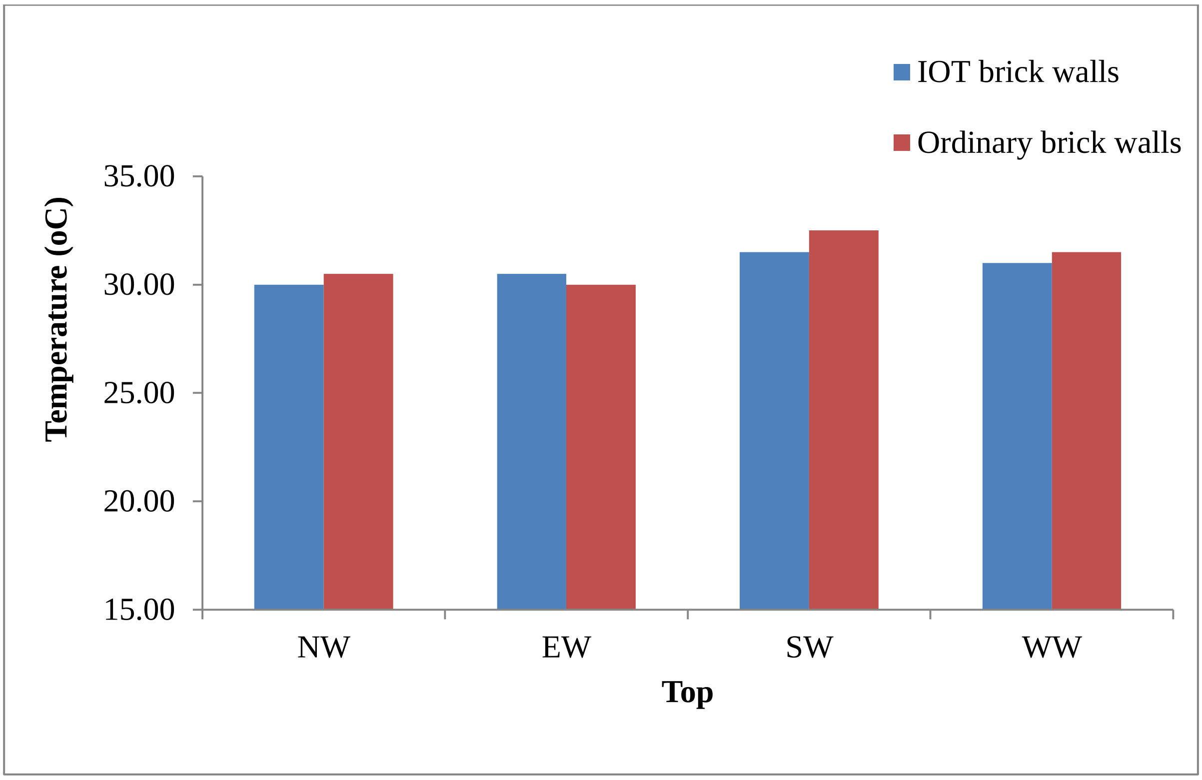

Figure 4.44 Temperature measured from 4pm to 6pm at top point of the outside walls

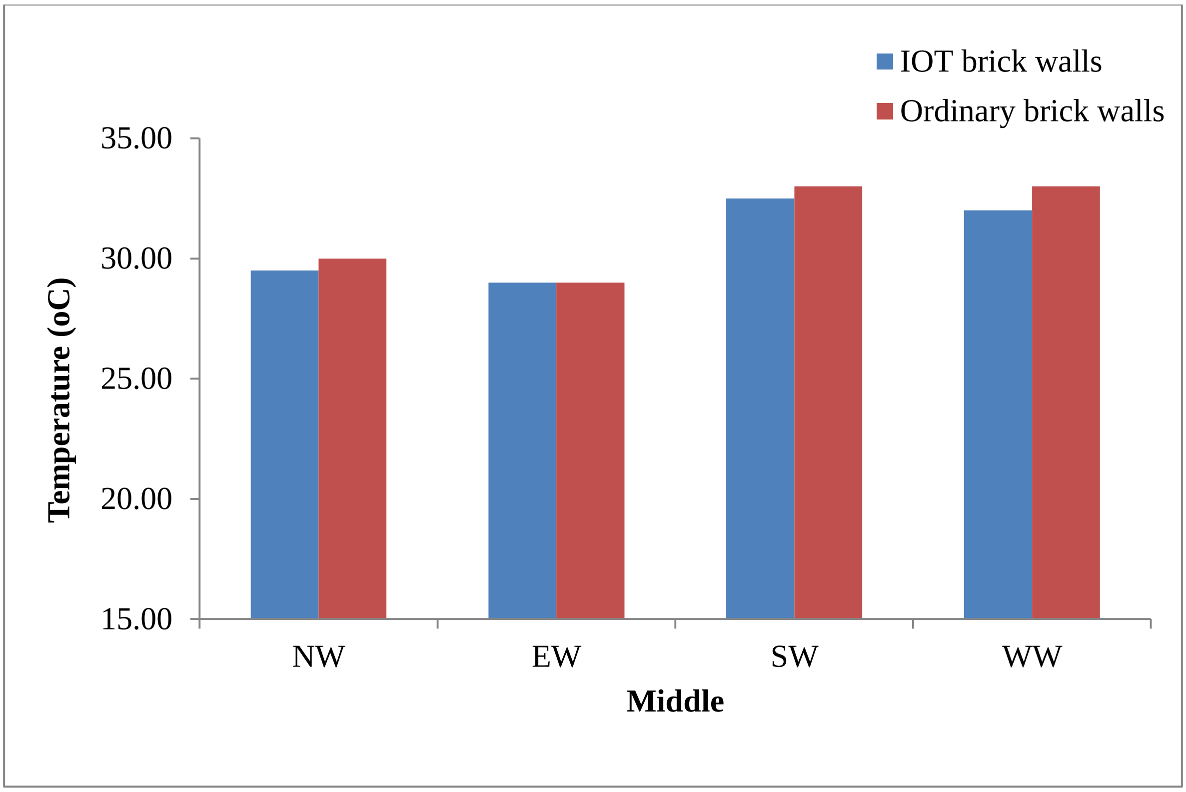

Figure 4.45 Temperature measured from 4pm to 6pm at middle point of the outside walls

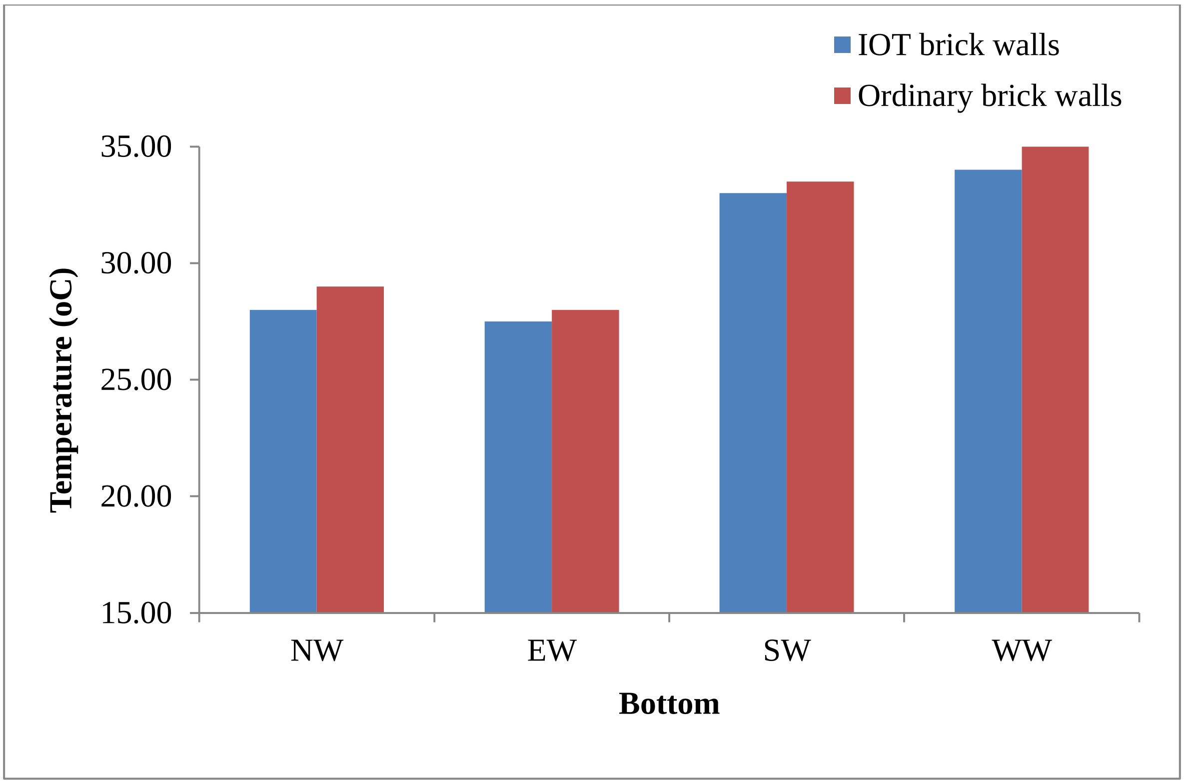

Figure 4.46 Temperature measured from 4pm to 6pm at bottom point of the outside walls

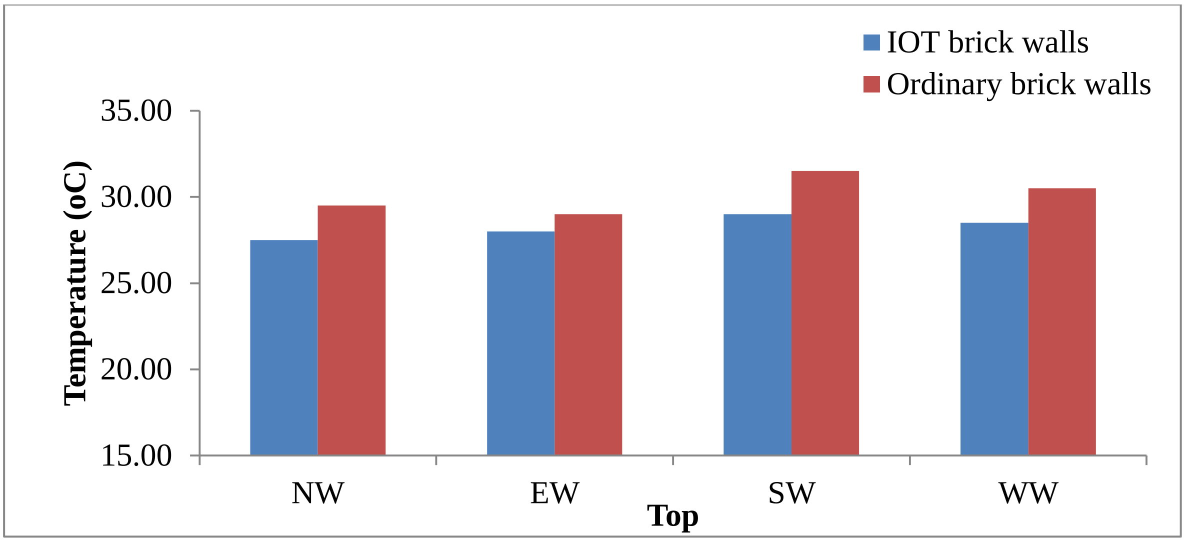

Figure 4.47 Temperature measured from 4pm to 6pm at top point of the inside walls

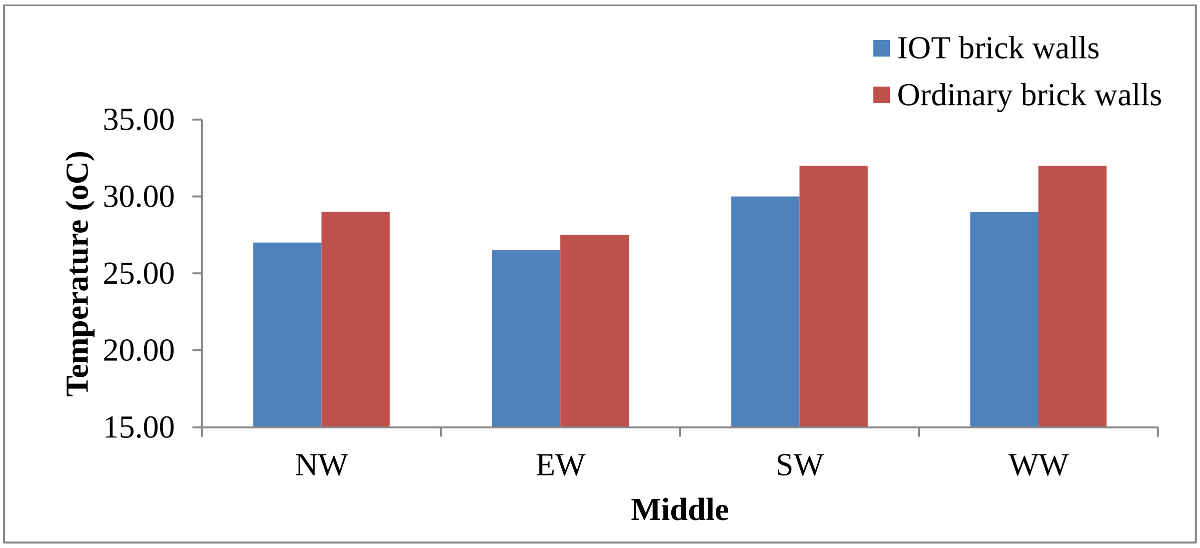

Figure 4.48 Temperature measured from 4pm to 6pm at middle point of the inside walls

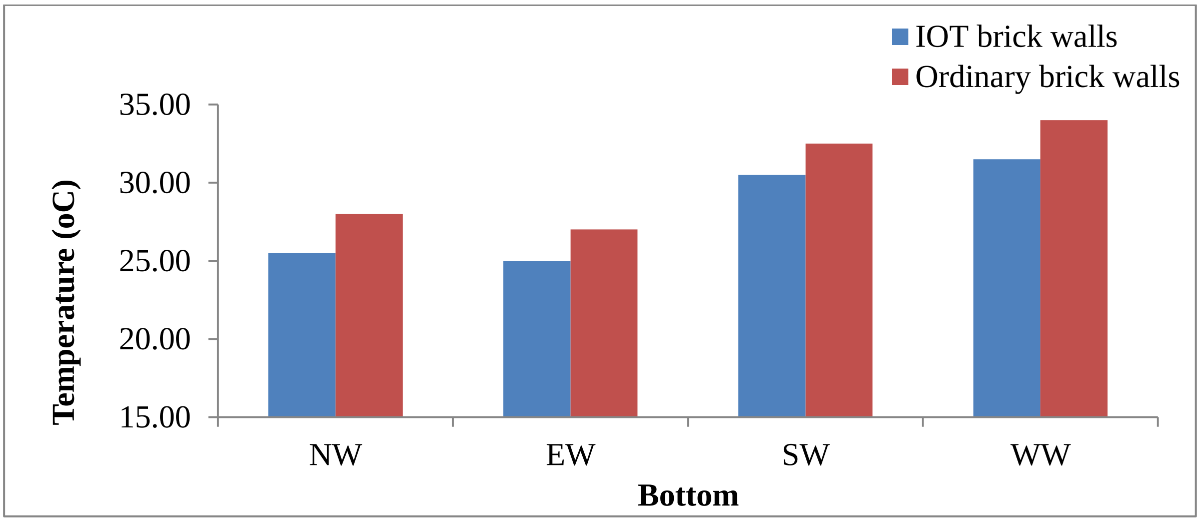

Figure 4.49 Temperature measured from 4pm to 6pm at bottom point of the inside walls

4.2.2.4 Temperature measurement of the room at 5minutes interval after plastering

The temperature variation in IOT-Perlite brick room and ordinary brick room after plastering are measured at a regular interval of 5 minutes for 55 minutes. It is noticed that the room temperature varies with a change in atmospheric temperature but maintain the average difference at all points of time. It is established that the temperature of the IOT – Perlite brick room is less by 2 – 2.50^{o}C compared to an ordinary brick room (Figure 4.50). Figure 4.51 shows the temperature response of proto type room for full day. This concludes that using perlite as an additive is given an advantage, which reduced the room temperature and obtained 0.5 ^{o}C further reduction compared to without plastering, which saves the energy consumption.

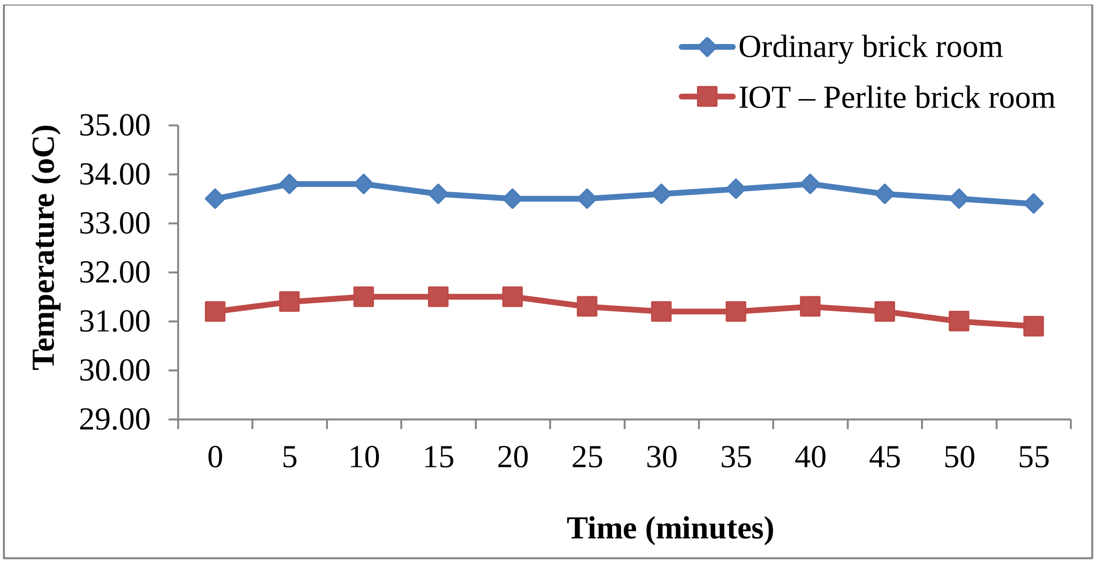

Figure 4.50 Temperature vs time after plastering of model rooms

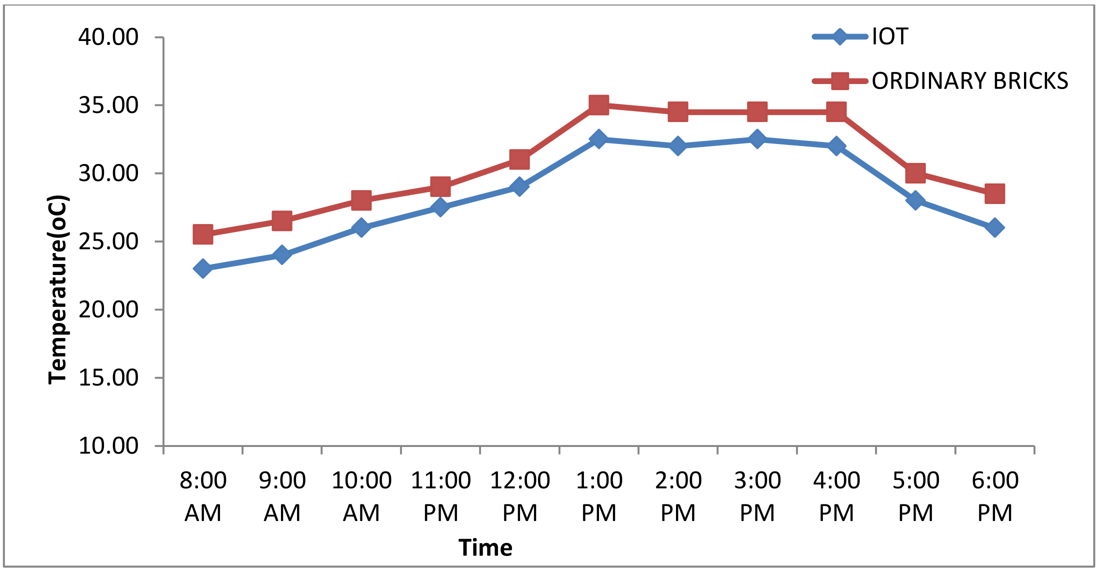

Figure 4.51 Temperature vs time for the day after plastering of model rooms

4.3 Cost Saving in terms of Energy Consumption

Percentage of energy or money saved by using IOT – Perlite bricks compared to ordinary bricks is analyzed and calculated with reference to the energy required by air conditioner to reduce the room temperature by 2°C, is presented in the Table 4.1. Air conditioner of 1.5 tonnes is considered for the calculation of percentage of saved energy. At atmospheric temperature 31°C, the room temperature of IOT – Perlite bricks and Ordinary bricks are 25°C and 27°C respectively in one of the selected trials and considered the IOT- perlite brick room temperature is less by 2°C compared to ordinary brick room.

As shown in Table 4.1, to maintain room temperature of 18°C as reference temperature, the electricity charges Rs.2633 per month. Similarly, to maintain 25 °C and 27 °C the electricity charges Rs. 2025 and Rs. 1823 respectively. The study has obtained the average room temperature for IOT- perlite brick room is 25 °C, which does not require air conditioner usually at this point. If the room needs to maintain temperature of 18 °C in IOT – Perlite brick room, when the temperature of IOT- perlite brick room is 25 °C the electricity charges will be Rs. 608 per month (Rs.2633- Rs.2025).

Accordingly, the room temperature of ordinary brick is 27 °C as an average obtained from the trails, the electricity charges are Rs. 1823 per month. If the room requires 18 °C, when the room temperature of ordinary brick is 27 °C, the electricity charges will be Rs. 810 per month (Rs.2633 - Rs.1823).

It concludes that the electricity charges of Rs. 202 per month is more in ordinary bricks room compared to IOT- perlite brick room. Hence, there is saving of 8% energy in the IOT- perlite brick room, in terms of electricity for room size of 48 cubic meter because of lower thermal conductivity in IOT- perlite bricks. The estimations are made as per the ready reckoner of The Energy and Resources Institute, TERI (https://www.livemint.com).

Table 4.1 Energy and cost savings at different AC temperature settings

Atmospheric temperature at 31^{o}C			
Room Temperature, ^{o}C	Total energy needed in Units, kWh/ day (when ambient temperature is 31^{o}C) (a)	Electricity cost of using an AC	
		(Rs. per day) (a) X 6.75	(Rs. per month) (b) X 30
		(b)	(c)
18	13.00	87.75	2,633
25	10.00	67.50	2,025
27	9.0	60.75	1,823

Assumptions for cost analysis:
AC: 1.5 tonnes, 5-star rated window AC;
Energy consumption of AC: 1.3KW/hr;
Electricity cost: Rs. 6.75 per unit;
AC functioning for 10 hours a day with each month having 30 days;

Note:
Savings in lower temperatures (<24^{o}C) – 6% for every 1^{o}C; Savings in higher temperatures (>24^{o}C) – 4% for every 1^{o}C; No other electricity consumption in the household (The Energy and Resources Institute, TERI).

The energy saved by difference in temperature calculated as per the source: the energy and resources Institute (TERI) and the calculation are based on controlled conditions like steady ambient temperature. The total electricity bill saved is only an approximate amount and will vary depending on room insulation, actual room temperature, outside room temperature throughout the day, compressor run time, Energy Efficiency Ratio (EER), room size, total number of the people in the room, etc; AC functioning for 8 months a year.

4.4 Economic Feasibility Study

In order to assess the economic feasibility of thermal efficient bricks proposed in this study, a systematic study is carried out. All the materials used in the brick are converted to the units of marketable price. Table 4.2 shows the estimated cost details of brick with perlite and Table4.3 shows the brick cost details without perlite. Based on the present price of the materials in the market, total cost of the brick is estimated.

Table 4.2 Cost analysis of bricks (with perlite)

Material percentage	**Cement (20%)**	**Sand (25%)**	**IOT (50%)**	**Perlite (5%)**	**Total (100)**
Quantity of material required for each brick	0.67Kg	0.85Kg	1.68Kg	0.16Kg	-
Cost per kg, Rs.	6.00	0.75	0.70	30.00	-
Cost of material per brick, Rs.	4.02	0.64	1.18	4.80	10.64
Labour cost, Rs.	-	-	-	-	2.90
Total cost of the brick, Rs.	-	-	-	-	13.54

Table 4.3 Cost analysis of bricks (without perlite)

Material percentage	**Cement (20%)**	**Sand (30%)**	**IOT (50%)**	**Total (100)**
Quantity of material required for each brick	0.727Kg	1.09Kg	1.82Kg	-
Cost per kg, Rs.	6.00	0.75	0.70	-
Cost of material per brick, Rs.	4.36	0.82	1.27	6.45
Labour cost, Rs.	-	-	-	2.90
Total cost of the brick, Rs.	-	-	-	9.35

Normal cost of the brick in the present market is Rs.14.00. Estimated cost of the brick with optimum combination is Rs. 13.54 and the cost of IOTs brick without perlite addition is Rs.9.35. In this study, Iron ore tailings is brought from Bellary at distance of approximately 400km for which the transportation cost is more and is considered with loading and unloading charges but if bricks are manufactured near the mining area then the considerable reduction will be achieved. In total there is marginal saving of 4% cost with perlite brick and a considerable savings of 38% with IOT bricks without perlite. The cost of IOTs and Perlite brick will be reduced, when the brick is prepared for construction in the vicinity of the mine area.

4.5 Development of Regression Models

Based on the large quantity of data generated, regression models were developed to predict various properties like density, compressive strength, water absorption and thermal conductivity. 70% of the data is used to develop models and the remaining data is used to validate the models.

4.5.1 Prediction of density

In order to predict the density, the input parameters considered are IOT (I), sand (S), perlite (P) and cement (C) in terms of percentage, also the input parameters are varied so as to obtain the correlation between the input and output parameters. Using ANOVA analysis Equation -4.1 is developed and the regression analysis is performed between actual and predicted values using Equation-4.1 and the value of regression co-efficient (R^2)found to be 0.83 which shows a very good correlation. From the analysis, it can be stated that cement is the most significant influence on density of brick followed by the other parameters IOT, sand and perlite. The parametric estimates are given in Table 4.4 and the analysis of variance (ANOVA) test summary given in Table 4.5 indicates that the model is robust as P values is less than 0.05. Figure 4.52 shows the regression fit between the observed values and predicted values.

Density (kg/m^3) = -27148 + 288.9 I + 285.8 S+ 201.3 P+ 303.3 C........ Equation (4.1)

Where,

I= Iron ore tailings, S= Sand, P= Perlite and C= Cement

Table 4.4 Parametric estimates for density of IOT – perlite brick

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	-27148	6831	-3.97	0.000	
IOT	288.9	68.2	4.24	0.000	2251.00
SAND	285.8	68.2	4.19	0.000	2626.00
PERLITE	201.3	68.6	2.93	0.006	76.00
CEMENT	303.3	68.3	4.44	0.000	301.00

Table 4.5 ANOVA summary for density of IOT – perlite brick

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	1460210	365053	39.26	0.000
IOT	1	166866	166866	17.94	0.000
SAND	1	163419	163419	17.57	0.000
PERLITE	1	80005	80005	8.60	0.006
CEMENT	1	183397	183397	19.72	0.000
Error	31	288277	9299		
Total	35	1748487			

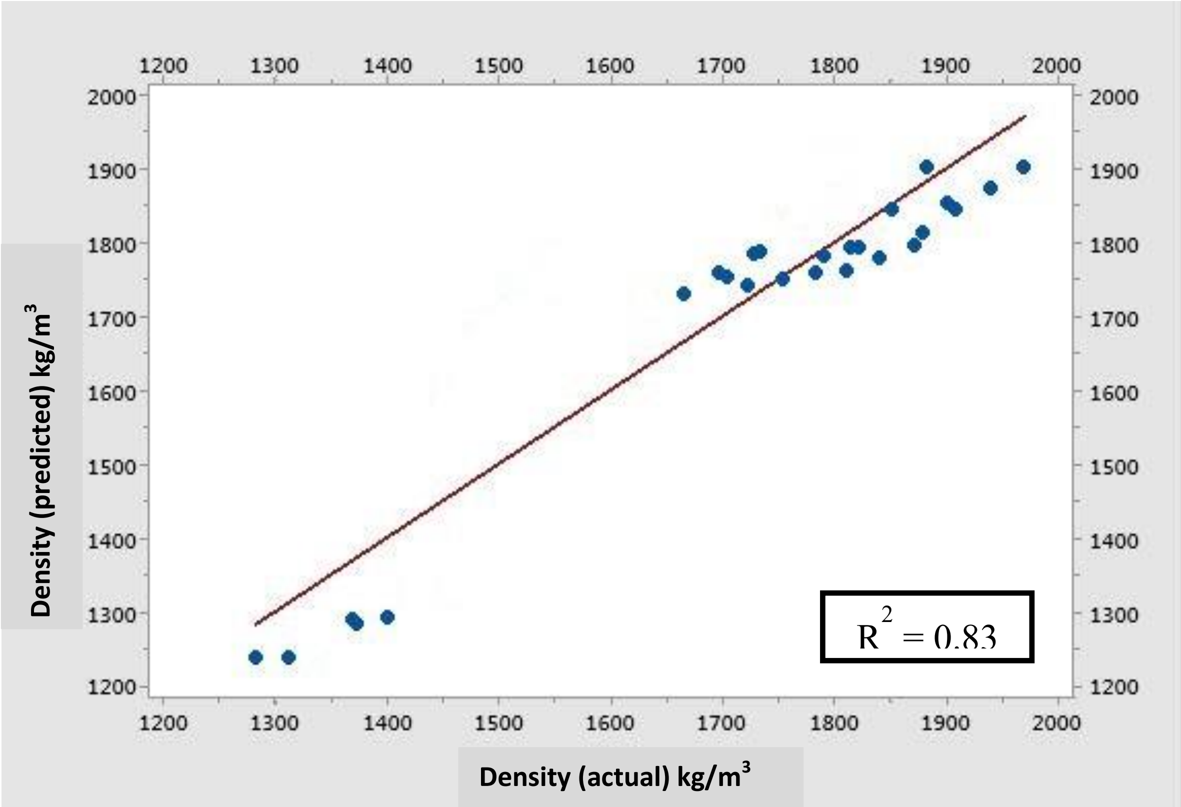

Figure 4.52 Relationship between predicted and measured values of density

4.5.2 Prediction of compressive strength

Considering all the input parameters IOT (I), sand (S), perlite (P) and cement (C) percentage composition as whole, the output parameter compressive strength in terms of MPa is predicted as shown in Equation 4.2. R^2 value for compressive strength was found to be 0.88 between actual and predicted values. Results from regression analysis reveal that the parameter perlite has significant contribution and cement has least contribution on compressive strength of brick. The other two input parameters which influence the compressive strength are sand and IOT. Figure 4.53 shows the variation between observed and predicted values for the compressive strength (MPa). The parametric estimates are given in Table 4.6 and the analysis of variance (ANOVA) test summary given in Table 4.7 indicates that the model is robust. The regression equation is:

Compressive Strength, (MPa) = 220.8 - 2.173 I - 2.203 S - 3.062 P -1.873 C **.......** Equation (4.2)

Where,

I= Iron ore tailings, S= Sand, P= Perlite and C= Cement

Table 4.6 Parametric estimates for compressive strength of IOT – perlite brick

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	220.8	63.5	3.48	0.002	
IOT	-2.173	0.634	-3.43	0.002	2251.00
SAND	-2.203	0.634	-3.48	0.002	2626.00
PERLITE	-3.062	0.638	-4.80	0.000	76.00
CEMENT	-1.873	0.635	-2.95	0.006	301.00

Table 4.7 Analysis of variance (ANOVA) for compressive strength of IOT – perlite brick

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	189.973	47.4933	59.14	0.000
IOT	1	9.440	9.4404	11.76	0.002
SAND	1	9.709	9.7094	12.09	0.002
PERLITE	1	18.501	18.5009	23.04	0.000
CEMENT	1	6.990	6.9898	8.70	0.006
Error	31	24.895	0.8031		
Total	35	214.869			

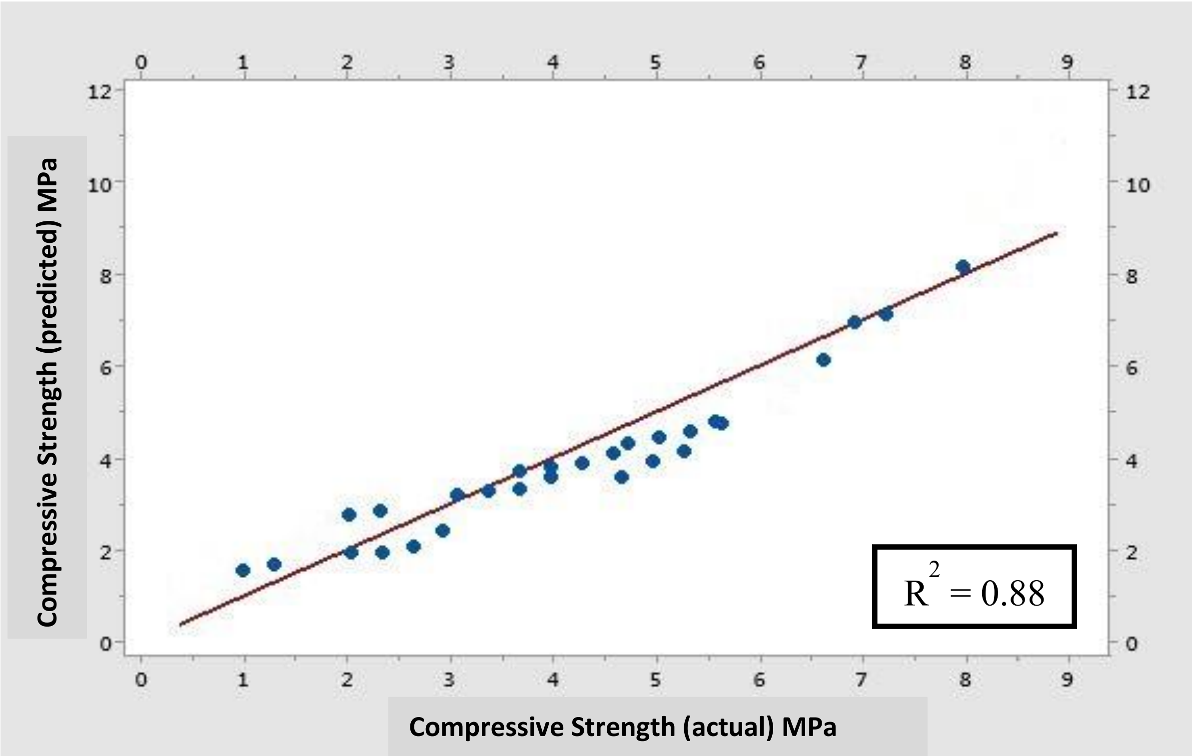

Figure 4.53 Relationship between predicted and measured values of compressive strength

4.5.3 Prediction of thermal conductivity

To predict thermal conductivity, the input parameters are IOT (I), sand (S), perlite (P) and cement (C) are used and Equation 4.3 is developed. The regression fit between actual and predicted values found to be of R^2 as 0.94, which shows very good correlation. Figure 4.54 shows the regression fit between the observed values and predicted values for output thermal conductivity. The parametric estimates are given in Table 4.8 and the analysis of variance (ANOVA) test summary given in Table 4.9 shows that all the independent variables were significant at 94% confidence level. The regression equation is:

Thermal Conductivity, (W/mk) = -9.13 + 0.1061 I + 0.1050 S - 0.0295 P + 0.1158 C **…….** Equation (4.3)

Where,

I= Iron ore tailings, S= Sand, P= Perlite and C= Cement

Table 4.8 Parametric estimates for thermal conductivity of IOT – perlite brick

Term	Coefficient	SE Coefficient	T-Value	P-Value	VIF
Constant	-9.13	6.04	-1.51	0.141	
IOT	0.1061	0.0602	1.76	0.088	3241.05
SAND	0.1050	0.0602	1.75	0.091	3781.50
PERLITE	-0.0295	0.0604	-0.49	0.628	109.56
CEMENT	0.1158	0.0613	1.89	0.068	447.52

Table 4.9 ANOVA for thermal conductivity of IOT – perlite brick

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	2.82423	0.706058	140.34	0.000
IOT	1	0.01563	0.015628	3.11	0.088
SAND	1	0.01532	0.015325	3.05	0.091
PERLITE	1	0.00120	0.001202	0.24	0.628
CEMENT	1	0.01797	0.017971	3.57	0.068
Error	31	0.15596	0.005031		
Total	35	2.98020			

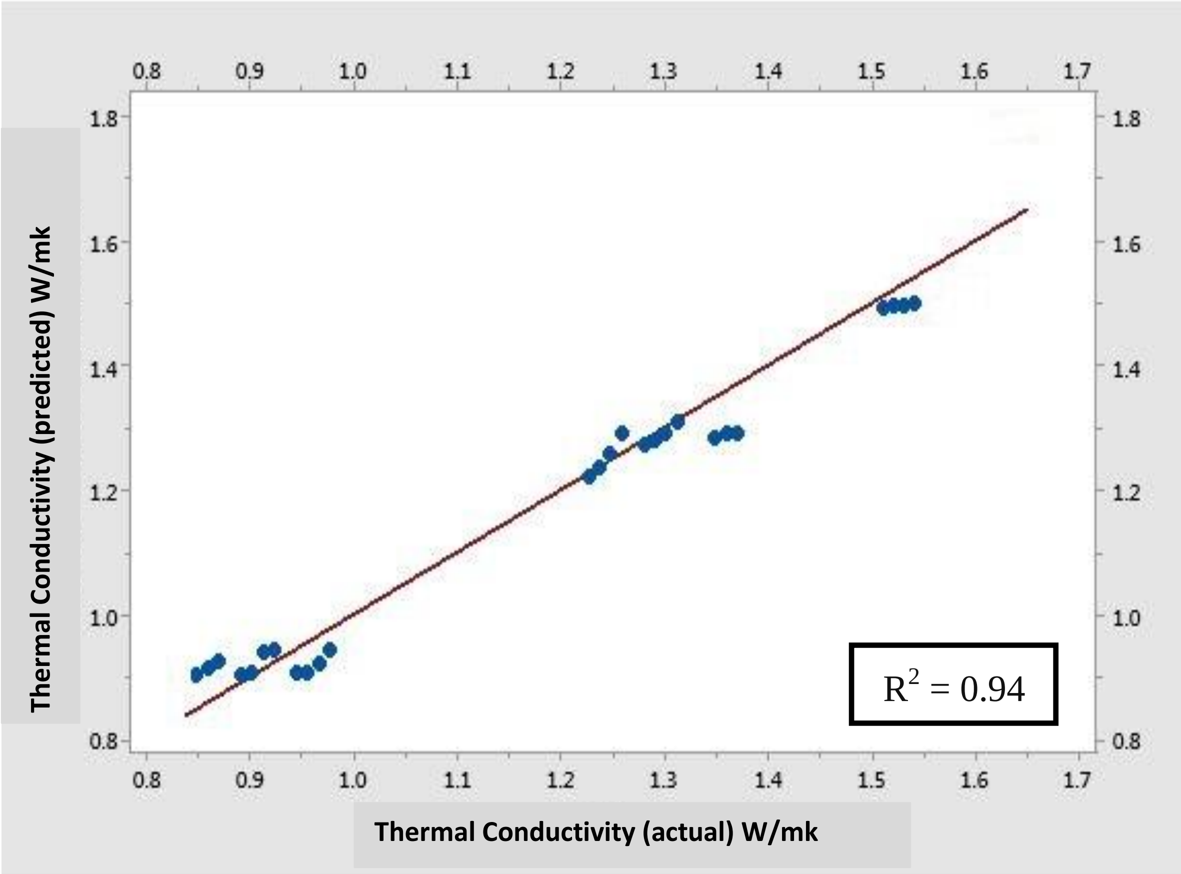

Figure 4.54 Relationship between predicted and measured values of thermal conductivity

CHAPTER-5

CHAPTER – 5

CONCLUSIONS AND SCOPE FOR FURTHER WORK

This chapter gives the conclusions based on large number of lab experiments carried out and pilot scale study, this chapter also recommends the future scope of work.

5.1 Conclusions

Based on the results obtained from the experimental studies, the following conclusions are drawn:

5.1.1 Material Properties

i. Physical properties of iron ore tailings, perlite, OPC 53 grade cement and river sand used for the research study are confirming to IS codes specifications. The specific gravity of IOT is 3.31 is high compared to that of river sand, with larger surface area having water absorption of 2.29%. Perlite is inorganic material with a porous structure due to which it absorbs high water content and has lower thermal conductivity.

ii. Chemical composition of the materials i.e., iron ore tailings, cement and perlite were determined and it was observed that, the material consist of major elements such as high percentage of Silicon dioxide (SiO_2), Aluminium oxide (Al_2O_3), Iron oxide (Fe_2O_3) and Calcium oxide (CaO).

5.1.2 Laboratory studies

- It is a general phenomenon that the density of bricks increases with increase in percentage of IOT and that is confirmed in the test results. The brick containing IOT replaced for sand in various percentages has produced the brick with density from 1587.36kg/m^3 to 1758.19 kg/$m^3$for 30% to 60% of IOT respectively with 20% cement and 5% perlite.

- The density of brick can be reduced by the addition of perlite which is proved in the test results. When perlite percentage increased from 0 to 5%, the density of bricks decreased from 1843.29 kg/m^3 to 1723.43 kg/m^3 for 50% IOT.

- Compressive strength of bricks increases with increase in percentage of IOT and cement. The compressive strength of the brick was 3.56MPa with 30% IOT and 10% cement increased to 11.19MPa when IOT is 60% with 20% cement. Increased perlite from 0% to 5% reduced the compressive strength from 10.45MPa to 3.89MPa respectively. The brick should obtain minimum 3.50MPa compressive strength to satisfy the IS specifications. Brick with 50% of IOT, 5% perlite and 20% cement satisfies the requirements of IS code in terms of compressive strength.

- Water absorption of brick should not be more than 20% as per IS code. The above conclusion of compressive strength combination is giving better water absorption values (14.50%), which satisfies the IS specification.

- No perceptible deposit of efflorescence was observed when there is 5% of perlite in brick. In the absence of perlite in brick, efflorescence was present. So, perlite addition is an added advantage in this regard.

- Thermal conductivity of the brick is substantially reduced by adding perlite 0% to 5% in bricks i.e. 1.782 W/mk to 0.920 W/mk respectively for 20% cement addition for 50% IOT.

- Brick of iron ore tailings and perlite have achieved good result in quality assessment tests like unconfined compressive strength (UCS), thermal conductivity, and in durability tests such as water absorption, density and efflorescence.

- The mixture of 5% perlite with 50% iron ore tailings, 20% cement and 25% sand has given an optimum proportion for brick production, to get better results on all tests.

5.1.3 Pilot Scale Study

i. Heat from the atmosphere is arrested at outside surface of the IOT – Perlite brick wall better than ordinary brick wall before passing through the bricks. It showed lower temperature at outside surface of the walls than the ordinary brick walls.

ii. Temperature of inside surface of the walls in the room is low by 1 to 2^{o}C in IOT – Perlite brick walls compared to that of ordinary brick walls.

iii. It is noticed that inside temperature of the room, constructed by IOT – Perlite bricks on an average is less by 2^{o}C compared to ordinary bricks. This observation proved the thermal efficiency of non-fired IOT – Perlite bricks.

iv. Mortar used in the construction of IOT – Perlite brick wall is of same proportion of brick materials, which is found suitable as it has given a homogenous structure.

v. After the plastering of the wall, IOT – Perlite brick room had lower room temperature by 2.5^{o}C compared to ordinary brick room, which is 0.5^{o}C to 1^{o}C further reduction in room temperature when it is compared to without plastering to IOT – Perlite brick wall.

vi. The room temperature of IOT – Perlite bricks is less by approximately 2^{o}C compared to ordinary brick room which saves around 8% of electricity.

vii. It was found that the manufacturing cost of IOT-Perlite brick will be approximately 4 % less than the cost of the bricks available in the market. But the bricks without perlite can be used in the load bearing walls will cost 38% less than the ordinary bricks which is substantial in reducing the cost of construction.

viii. Though the economic advantage is nominal in IOT-Perlite bricks, the use of IOT in bricks is a great advantage for construction as well as for mining sector. In addition to the above, usage of mine waste in the form of iron ore tailings reduce the burden on depleting naturally available river sand and clay, on the other hand, disposal and maintenance cost of tailings will be a big saving to the mining and mineral industry and immediate use of IOT without storing reduces the environmental effect on the surroundings. As the bricks are non-fired, it results in lower embodied energy and also acts as energy conservative. Manufacturing of brick will not have any effect on the environment.

5.1.4 Statistical analysis

Regression models were developed for each of the properties tested in laboratory scale. The equations developed were formed to be robust and statistically fit for prediction of the properties. R^2 values obtained for density, compressive strength and thermal conductivity were 0.83, 0.88 and 0.94 respectively show a very good correlation. From the analysis, it can be stated that cement is the most significant influence on density of brick and the result from regression analysis of compressive strength reveals that the parameter perlite has significant contribution and cement has least contribution.

5.2 Scope for Further Work

1. Further study on the optimized proportion of this brick by adding strengthening additives to achieve more benefits can be explored.

2. It warrants an extended study on larger size as of blocks (500X200X100mm, 500X200X150mm) to reduce the joints using perlite to make the construction material more economical, strong and durable.

3. In this research, solid bricks are tested and constructed the room by using IOT – perlite solid bricks, so it can be tried for hallow brick and grouted hallow brick.

4. Wetting-drying cycles test, erosion test, Freezing/thawing cycles test as durability tests of the IOT – Perlite bricks can be studied for a longer duration.

REFERENCES

REFERENCES

Abdulrahman, H. S., (2015). "Potential use of iron ore tailings in sand crete block making." *International Journal of Research in Engineering and Technology*, 4(4), 409-414.

Anand, Kumar and Omendra, Singh, (2016). "Indian iron ore scenario: low grade iron ore beneficiation." MECON Limited, Ranchi, http://www.meconlimited.co.in/writereaddata/MIST_2016/sesn/tech_1/5.pdf, last accessed Sept 2019.

Arici, M., Yilma, B., Karabay, H., (2016). "Investigation of heat insulation performance of hollow clay bricks filled with perlite." *International Conference on Computational and Experimental Science and Engineering, (ICCESEN 2015),* Vol. 130, 266-268.

ArunRaja, L., Arumugam, M., Malaichamy, K., (2017). "Mechanical properties of light weight bricks using perlite and lime material." *SSRGInternational Journal of Civil Engineering,* special issue, 106-113.

Bulent, U., (2010). "Use of perlite as a pozzolanic addition in lime mortar." *Gazi University Journal Science*, 23(3), 305-313.

Borvorn, Israngkura, Na, Ayudhya, (2011). "Compressive and splitting tensile strength of autoclaved aerated concrete (ACC) containing perlite aggregate and polypropylene fiber subjected to high temperatures." *Songklanakarin Journal of Science and Technology,* 33(5), 555-563.

Benk, A., Coban, A., (2012). "Possibility of production lightweight heat insulating bricks from pumice and H_3PO_4 or NH_4NO_3 hardened molasses binder." *Ceramics International,* 38(3), 2283-2293.

Bindiganavile, V., Batool, F., and Suresh, N., (2012). "Effect of flyash on thermal properties of cement based foams evaluated by transient plane heat source." *The Indian Concrete Journal*, 86(11), 7-14.

Bullibabu, Kancharla& Ali, Abid, M.D., (2018). "Production and characterization of low thermal conductivity clay bricks by admixture of bagasse and perlite." *International Journal of Mechanical and Production Engineering Research and Development, (IJMPERD),* 8(3), 809-816.

Beatryz, C., Mendes, Leonardo, G., Pedroto, Mauricio, P.F., Fontes, Jose, Carlos, L., Ribeiro, Carlos, M.F., Vieira, Anderson, A., Pacheco, Afonso, R.G., de, Azevedo, (2019). "Technical and environmental assessment of the incorporation of iron ore tailings in construction clay bricks." *Construction and Building Materials,* Vol. 227.

Bureau of Indian Standards (BIS). Determination of compressive strength – Method of tests of burnt clay building bricks. IS: 3495 (Part 1): New Delhi, India; 1992.

Bureau of Indian Standards (BIS). Determination of water absorption – Method of tests of burnt clay building bricks. IS: 3495 (Part 2): New Delhi, India; 1992.

Bureau of Indian Standards (BIS). Determination of efflorescence – Method of tests of burnt clay building bricks. IS: 3495 (Part 3): New Delhi, India; 1992.

Bureau of Indian Standards (BIS). Method for the determination of thermal conductivity of thermal insulation materials – Two slab, guarded hot plate method. IS: 3346: New Delhi, India; 1980.

Bureau of Indian Standards (BIS). 53 grade ordinary portland cement specification. IS: 12269: New Delhi, India; 2013.

Bureau of Indian Standards (BIS). Sand for masonry mortars specification. IS: 2116: New Delhi, India; 1980.

Celik, M., H. and Durmaz, M., (2012). "The study of compressive strength in different cement types and dosages of concretes made by using 60% pumice and 40% perlite." *Contemporary Engineering Sciences,* 5(6), 287 – 293.

Carrasco, E.V.M., Mantilla, J.N.R., Esposito, T., Moreira, L.E., (2013). “Compression performance of walls of interlocking bricks made of iron ore byproducts and cement.” *International Journal of Civil & Environmental Engineering,* 13(3), 56-62.

Chaouki, Sadik, Abderrahman, Albizane, Iz-Eddine, EI., Amrani, (2013). “Production of porous fire brick from mixture of clay and recycled refractory waste with expanded perlite addition.” *J. Material Environmental Science,* 4(6), 981-986.

Celik, A.G., (2014). “Investigation on characteristic properties of potassium borate and sodium borate blended perlite bricks.” *Journal of cleaner production,* Vol. 102, 88-95.

Chuanmeng, Yang, Chong, Cui and Juan, Qin, (2014). “Recycling of low-silicon iron ore tailings in the production of lightweight aggregates.” *Ceramics International,* 41(1), 1213-1221.

Central Pollution Control Board, 2007. “Compressive industrial document on iron ore mining.” *Ministry of Environment and Forests, Govt. of India, New Delhi,* http://www.indiaenvironmentportal.org.in/files/iron_ore_mining.pdf.

Das, S.K., Kumar, S., Ramachandra, Rao, P., (2000). “Exploitation of iron ore tailing for the development of ceramic tiles,” *Waste Management*, 20(8), 725-9.

Demir, M., Orhan, (2004). “An investigation on the production of construction brick with perlite addition.” *Key Engineering Materials,* Vols. 264-268, 2161-2164.

Ellen, Bau, (2010). “Black carbon from brick kilns.” *Environmental Science,* Presentation for Clean Air Task Force.

Figen, Balo, Aynur, Ucar and Halit, Lutfi, Yucel, (2010). “Development of the insulation materials from coal, flyash, perlite, clay and linseed oil.” *Ceramics – Silikaty,* 54(2), 182-191.

Francis, A., Kuranchie, Sanjay, K., Shukla, Daryoush, Habibi, (2014). "Utilization of iron ore tailings for the production of geo polymer bricks." *International Journal of Mining, Reclamation and Environment*, 30(2), 92–114, http://dx.doi.org.

Giri, Babu, S.V. Krishnaiah, S., (2018). "Manufacturing of eco-friendly brick: A critical review." *International Journal of Computational Engineering Research, (IJCER),* Vol. 08, 24-32.

Gonzalez, E., Galan, A., Miras, M.A., Vazquez, (2011). "CO_2 emissions derived from raw materials used in brick factories: Applications to andalusia (Southern Spain)." *Applied by Clay Science*, 52(3), 193-198.

Georgiev, Angel, Albena, Yoleva, Stoyan, Djambazov, Dimitar, Dimitrovand Valentina Ivanova, (2017). "Effect of expanded vermiculite and expanded perlite as pore forming additives on the physical properties and thermal conductivity of porous clay bricks," *Journal of Chemical Technology and Metallurgy*, 53(2), 275-280.

Government of India, Ministry of Mines India Bureau of Mines (2018). *Indian Minerals Yearbook 2017, Perlite* (Part-III: Mineral Reviews), 56^{th} Edition.

Government of India, Ministry of Mines India Bureau of Mines (2019). *Indian Minerals Yearbook 2018, Iron Ore* (Part-III: Mineral Reviews), 57^{th} Edition.

Hammond, A.A., (1988). "Mining and quarrying wastes: A critical review." *Engineering Geology,* 25 (1), 17-31.

Iiker, Bekir, Topcu, Burak, Isikdag, (2006). "Manufacture of high heat conductivity resistant clay bricks containing perlite." *Building and Environment*, 42(10), 3540-3546.

Jilla, Naveen, Kancharla, Bullibabu, Veeranjaneyulu, K., Abidali, (2018). "Production and analysis of composite construction materials with admixture of coal – bagasse based fly ash and perlite by ANSYS approach." *International Research Journal of Engineering & Technology*, 5(8), 735 – 739.

Kumar, S., Kumar, R., Amitava, B.. (2006). "Innovative methodologies for the utilization waste from metallurgical and allied industries." *Resources Conservation and Recycling*, 48(4), 301-314.

Kshitija, K., Vikrant, S., Mujahed, S., Mahesh, K., Mahendra, C., and Sagar, S., (2015). "Use of iron ore tailings as a construction material." *International Journal of Conceptions on Mechanical and Civil Engineering*, 1(2), 1 – 21.

Lanzon, M. and Garcia-Ruiz, P. A., (2008). "Light-weight cement mortars: Advantages and inconveniences of expanded perlite and its influence on fresh and hardened state and durability." *Construction and Building Materials,* 22(8), 1798-1806.

Likith, N.P., Manjunatha, Siddesh, S.S., Manjunath, K.M., ShivakumarHadimani and Shivkumar, B. (2017). "Manufacturing of building blocks by utilizing of iron ore tailings." *International Journal of Engineering Science and Computing,* 7(5), 12274 – 12277.

Li, Runfeng, Yang, Zhou, Cuiwei, Li, Shibo, Li and Zhenying, Huang, (2019). "Recycling of industrial waste iron ore tailings in porous bricks with low thermal conductivity." *Construction and Building Materials,* Vol. 213, 43-50.

Michael, Chusid, Steven, H., Miller, Julie, Rapport, (2009). "The building bricks of sustainability." *The Construction Specifier,* Vol. 1, 30-40. https://www.researchgate.net/publication/285295384_The_building_brick_of_sustainability

Mohanty, M., Dhal, N. K., Patra, P., Das, B., and Reddy, P. S. R., (2010). "Phytoremediation: A novel approach for utilization of iron-ore wastes," *In Reviews of Environmental Contamination and Toxicology,* Vol. 206, 29-47.

Mangalpady, A., (2012). "Utilization of iron ore tailings in manufacturing of paving blocks for eco- friendly mining." *IC –GWBT2012, Ahmad Dahlan University*, 23-24.

Modi, Jemish, Sujeet Bharti, V., Aruna, M., and HarshaVardhan, (2014). “Utilization of mining wastes in manufacturing of bricks.” *Conference: National Seminar on Recent Trends in Mechanized Mining, Kothagudem, Telangana*, 27-28

Mohajer. A.S., Ghanbarnezhad, S., Sharifi, L., Mirhosseini, S.H., Irvani, Y.M., (2014). “Production of lightweight refractory insulation panels on the basis of perlite.” *International Journal of Research Science and Management*, 1(1), 1-12.

MalekJedidi, OmraneBenjeddou, ChokriSoussi. (2015). “Effect of expanded perlite aggregate dosage on properties of lightweight concrete”. *Jordan Journal of Civil Engineering*, 9(3), 278-291.

Mueena, Samar and Shweta, Saxena, (2016). “Study of chemical and physical properties of perlite and its application in India,” *International Journal of Science Technology and Management*, 5(4), 70-80.

Namratha, M., Aruna, R. and Saraswathi, M., (2014). “Strengthening of fly ash bricks by ironite.” *IOSR Journal of Mechanical and Civil Engineering*, 11(3), 21-26.

Nagaraj, H.B., Rajesh, A., Sravan, M.V., (2016). “Influence of soil gradation proportion and combination of admixtures on the properties and durability of CSEBS.” *Construction and Building Materials*, Vol. 110, 135-144.

Nithiya, R., Chris, Anto, L., Vinodh, K.R. and Anbalagan, C., (2016). “Experimental investigation on bricks by using various waste materials.” *International journals of latest trends in engineering and technology (IJLTET),* 6(3), 395-402.

Prahallada, M.C. and Shanmuka, K.N., (2014). “Stabilized iron ore tailings block an – environmental friendly construction material.” *International Journal of IT, Engineering and Applied Sciences Research*, 3(4), 2319 – 4413.

Prem, Kumar, W. P., Ananthya, M. B., Vijay, K., (2014). “Effect of replacing sand by iron ore tailings on the compressive strength of concrete and flexural strength of reinforced concrete blocks”. *International Journal on Research in Engineering and Technology,* 3(7), 1374-1376.

Ravi, Kumar, C.M., Anil, Kumar, Prashanth, M.H. and Venkat, Reddy, D., (2012). “Experimental studies on iron ore tailings based interlocking paves blocks.” 5(3), 501-504.

Sengul, O., Zaizi, S., Karaosmanogu, F. and Tasdemir, M. A., (2011). “Effect of expanded perlite on the mechanical properties and thermal conductivity of lightweight Concrete.” *Energy and Buildings,* 43(2-3), 671–676.

Sujing, Zhao, Junjiang, Fan and Wei, Sun, (2013). “Utilization of iron ore tailings as fine aggregate in ultra – high performance concrete.” *Construction and Building Materials,* Vol.50, 540 – 548.

Skanda, Kumar, B.N., (2014). “Utilzation of iron ore tailings as replacement to fine aggregates in cement concrete pavements.” *International Journal of Research in Engineering and Technology,* 3(7), 369 – 376.

Shankarananth, S. and Jaivignesh, B., (2016). “Experimental study on the use of glass powder, GGBS, & perlite in fly ash brick.” *International Journal of Advanced Research,* 4(4), 1381-1387.

Shreekant, R.L., Aruna,M., and Harsha, Vardhan, (2016). “Utilization of iron ore waste in brick making for the construction industry.” *International Journal of Earth Sciences and Engineering,* 9(2), 450-455.

Satakhun, Detphan, Tanakorn, Phoo-ngernkham, Vanchai, Sata, Chudapak, Detphan and Prinya, Chindaprasirt, (2018). “Portland cement containing fly ash, expanded perlite, and plasticizer for masonry and plastering mortars.” *International Journal of GEOMATE,* 15(48), 107-113.

Toledo, R., Dos, Santos, D. R., Faria, R. T., Carrio, J. G., Avler, L. T. and Vargas, H., (2004). "Gas release during clay firing and evolution of ceramic properties." *Applied clay science*, Vol.27, 151-157.

Ullas, S.N., Venkatarama, Reddy, B.V., Nanjunda, Rao, K.S., (2010). "Characteristics of masonry units from iron ore tailings." *International Conference on Sustainable Built Environment*, *Kandy*, 108-114.

Ugama, T. I., Ejeh, S. P., (2014). "Iron ore tailings as fine aggregate in mortar used for Masonry." *International Journal of Advances in Engineering and Technology*, 7(4), 1170-1178.

Uluer, O., Aktas, M., Karaagac, I., Durmus, G., Khanlari, A., Agbulut, U. and Celik, D., N., (2018). "Mathematical calculation and experimental investigation of expanded perlite based heat insulation materials thermal conductivity values." *Journal of Thermal Engineering*, 4(5), 2274 – 2286.

Xiaoyan, Huang, Ravi, R,. and Victor Li, (2013). "Feasibility study of developing green ECC using iron ore tailings powder as cement replacement." *Journal of Materials in Civil Engineering*, 25(7), 923 – 931.

Xu, F., Peng, C., Zhu, J. and Chen, J., (2016). "Design and evaluation of polyester fiber and SBR latex compound – Modified perlite mortar with rubber powder." *Construction and Building Materials*, 127, 751-761.

Yongliang, Chen, Yimin, Zhang, Tiejun, Chen, Yunliang, Zhao, Shenxu, Bao, (2010). "Preparation of eco-friendly construction bricks from hematite tailings." *Construction and Building Materials*, 25, 2107-2111.

Yisa, G. L., Akanbi, D. O., Agbonkhese, O., Ahmed, M. K. and Sani, J. E., (2016). "Effect of iron ore tailing on compressive strength of manufactured laterite bricks and its reliability estimate." *Civil and Environmental Research*, 8(8), 49-58.

Zulkifeli, M. and Saman, H., (2016). "Compressive and flexural strength of expanded perlite aggregate mortar subjected to high temperatures." *International Conference on Applied Physics and Engineering (ICAPE2016)*, Malaysia.

https://shodhganga.inflibnet.ac.in/bitstream/10603/152177/16/9.%20chapter-1.pdf, last accessed on 20th Sep 2017

http://www.keltechenergies.com/perlite-products.html, last accessed on 5th Dec. 2018

http://www.hertig.com.ar/PDFWeb/Productos/TemperaturaAireHumedadPh/Termometros/VA6502.pdf, last accessed on 18th Aug 2019

https://www.primusthai.com/uploads/files_th/CENTER350_352.pdf, last accessed on 18th Aug2019

https://www.acchelp.in/purchase_managers_certificate.html, last accessed on 14th April 2020

https://www.researchgate.net/profile/Isaac_Animasaun/post/How_can_i_calculate_thermal_conductivity_of_porous_ceramics_without_effect_of_porosity/attachment/5cefc672cfe4a7968da5529c/AS%3A764228906541056%401559217778018/download/chapter-16.pdf, last accessed on 10th Sep 2020

APPENDIX

APPENDIX A

Table A – 1 Dry density of bricks of varying percentage of raw materials

Sl. No	Percentage of Raw materials, %				No. of Samples	Dry Weight, kg	Average Dry Weight, kg	Average Mass Density, kg/m^3
	IOT	Sand	Perlite	Cement				
1	30	60	0	10	6	3.4	3.404	1754.32
						3.404		
						3.408		
						3.399		
						3.409		
						3.404		
2	40	50	0	10	6	3.41	3.472	1789.11
						3.398		
						3.385		
						3.533		
						3.526		
						3.58		
3	50	40	0	10	6	3.577	3.577	1843.29
						3.577		
						3.584		
						3.578		
						3.558		
						3.579		
4	60	30	0	10	6	3.678	3.685	1898.87
						3.672		
						3.704		
						3.685		
						3.683		
						3.687		
5	30	58	2	10	6	3.334	3.331	1716.45
						3.322		
						3.331		
						3.332		
						3.331		
						3.336		

Table A – 1 Dry density of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Dry Weight, kg	Average Dry Weight, kg	Average Mass Density, kg/m^3
	IOT	Sand	Perlite	Cement				
6	40	48	2	10	6	3.366	3.36	1731.6
						3.354		
						3.36		
						3.366		
						3.354		
						3.36		
7	50	38	2	10	6	3.401	3.412	1758.22
						3.423		
						3.412		
						3.412		
						3.401		
						3.423		
8	60	28	2	10	6	3.342	3.462	1783.96
						3.522		
						3.392		
						3.545		
						3.444		
						3.527		
9	30	55	5	10	6	2.391	2.399	1236.19
						2.399		
						2.407		
						2.391		
						2.399		
						2.407		
10	40	45	5	10	6	2.4	2.401	1237.23
						2.399		
						2.404		
						2.401		
						2.399		
						2.403		

Table A – 1 Dry density of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Dry Weight, kg	Average Dry Weight, kg	Average Mass Density, kg/m^3
	IOT	Sand	Perlite	Cement				
11	50	35	5	10	6	2.4	2.412	1242.89
						2.424		
						2.412		
						2.412		
						2.4		
						2.424		
12	60	25	5	10	6	2.49	2.492	1284.12
						2.494		
						2.492		
						2.49		
						2.494		
						2.492		
13	30	55	0	15	6	3.46	3.461	1783.44
						3.462		
						3.461		
						3.46		
						3.462		
						3.461		
14	40	45	0	15	6	3.523	3.479	1792.72
						3.516		
						3.458		
						3.475		
						3.464		
						3.438		
15	50	35	0	15	6	3.58	3.582	1845.79
						3.582		
						3.584		
						3.584		
						3.582		
						3.58		

Table A – 1 Dry density of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Dry Weight, kg	Average Dry Weight, kg	Average Mass Density, kg/m^3
	IOT	Sand	Perlite	Cement				
16	60	25	0	15	6	3.585	3.691	1901.96
						3.734		
						3.694		
						3.579		
						3.691		
						3.863		
17	30	53	2	15	6	3.378	3.378	1740.67
						3.37		
						3.386		
						3.378		
						3.386		
						3.37		
18	40	43	2	15	6	3.395	3.395	1749.45
						3.262		
						3.44		
						3.395		
						3.345		
						3.533		
19	50	33	2	15	6	3.414	3.414	1759.32
						3.128		
						3.589		
						3.665		
						3.426		
						3.264		
20	60	23	2	15	6	3.482	3.482	1794.27
						3.48		
						3.484		
						3.476		
						3.489		
						3.482		

Table A – 1 Dry density of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Dry Weight, kg	Average Dry Weight, kg	Average Mass Density, kg/m^3
	IOT	Sand	Perlite	Cement				
21	30	50	5	15	6	2.576	2.499	1287.73
						2.448		
						2.474		
						2.5		
						2.495		
						2.502		
22	40	40	5	15	6	2.536	2.504	1290.30
						2.558		
						2.42		
						2.504		
						2.499		
						2.505		
23	50	30	5	15	6	2.536	2.544	1310.92
						2.518		
						2.578		
						2.54		
						2.548		
						2.544		
24	60	20	5	15	6	2.57	2.595	1337.19
						2.588		
						2.626		
						2.585		
						2.602		
						2.598		
25	30	50	0	20	6	3.52	3.52	1813.85
						3.636		
						3.421		
						3.52		
						3.443		
						3.58		

Table A – 1 Dry density of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Dry Weight, kg	Average Dry Weight, kg	Average Mass Density, kg/m^3
	IOT	Sand	Perlite	Cement				
26	40	40	0	20	6	3.484	3.582	1845.79
						3.592		
						3.466		
						3.61		
						3.582		
						3.758		
27	50	30	0	20	6	3.628	3.635	1873.12
						3.612		
						3.666		
						3.633		
						3.646		
						3.626		
28	60	20	0	20	6	3.682	3.692	1902.48
						3.745		
						3.688		
						3.692		
						3.663		
						3.68		
29	30	48	2	20	6	3.306	3.42	1762.32
						3.577		
						3.461		
						3.325		
						3.429		
						3.422		
30	40	38	2	20	6	3.452	3.452	1778.81
						3.45		
						3.454		
						3.452		
						3.45		
						3.454		

Table A – 1 Dry density of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Dry Weight, kg	Average Dry Weight, kg	Average Mass Density, kg/m^3
	IOT	Sand	Perlite	Cement				
31	50	28	2	20	6	3.485	3.485	1795.81
						3.48		
						3.495		
						3.48		
						3.485		
						3.485		
32	60	18	2	20	6	3.597	3.597	1853.53
						3.59		
						3.611		
						3.597		
						3.59		
						3.597		
33	30	45	5	20	6	3.045	3.08	1587.36
						3.080		
						3.095		
						3.080		
						3.080		
						3.080		
34	40	35	5	20	6	3.250	3.257	1678.32
						3.264		
						3.257		
						3.257		
						3.264		
						3.25		
35	50	25	5	20	6	3.362	3.362	1732.43
						3.363		
						3.362		
						3.361		
						3.361		
						3.363		
36	60	15	5	20	6	3.412	3.412	1758.19
						3.411		
						3.400		
						3.425		
						3.412		
						3.412		

Table A – 2 Water absorption of bricks of varying percentage of raw materials

Sl. No	**Percentage of Raw materials, %**				**No. of Samples**	**Weight of Dry brick, kg**	**Avg. Weight of Dry brick (M_1), kg**	**Weight of Immersed brick, kg**	**Avg. Weight of Immersed brick (M_2), kg**	**Water absorption, %** $[(M_2-M_1)/M_1]x100$
	IOT	**Sand**	**Perlite**	**Cement**						
1	30	60	0	10	6	3.532	3.532	4.158	4.167	17.99
						3.53		4.167		
						3.532		4.176		
						3.534		4.158		
						3.53		4.167		
						3.534		4.176		
2	40	50	0	10	6	3.455	3.567	4.313	4.22	18.30
						3.567		4.101		
						3.567		4.22		
						3.601		4.265		
						3.462		4.166		
						3.75		4.255		
3	50	40	0	10	6	3.641	3.641	4.325	4.329	18.91
						3.627		4.334		
						3.641		4.329		
						3.652		4.329		
						3.641		4.325		
						3.644		4.334		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
4	60	30	0	10	6	3.5	3.522	4.252	4.274	21.30
						3.525		4.271		
						3.516		4.268		
						3.523		4.275		
						3.52		4.272		
						3.548		4.3		
5	30	58	2	10	6	3.67	3.675	4.4	4.404	19.85
						3.675		4.41		
						3.68		4.404		
						3.375		4.4		
						3.374		4.41		
						3.376		4.404		
6	40	48	2	10	6	3.686	3.686	4.42	4.428	20.14
						3.68		4.436		
						3.692		4.428		
						3.386		4.42		
						3.68		4.436		
						3.692		4.428		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
7	50	38	2	10	6	3.69	3.697	4.46	4.464	20.76
						3.704		4.464		
						3.697		4.468		
						3.69		4.46		
						3.704		4.468		
						3.697		4.464		
8	60	28	2	10	6	3.72	3.725	4.579	4.579	22.92
						3.73		4.588		
						3.725		4.57		
						3.72		4.579		
						3.73		4.588		
						3.725		4.57		
9	30	55	5	10	6	3.7	3.701	4.504	4.503	21.66
						3.701		4.503		
						3.702		4.502		
						3.7		4.504		
						3.701		4.503		
						3.702		4.502		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
10	40	45	5	10	6	3.709	3.71	4.535	4.538	22.32
						3.71		4.541		
						3.711		4.538		
						3.709		4.541		
						3.71		4.538		
						3.711		4.535		
11	50	35	5	10	6	3.37	3.374	4.13	4.139	22.67
						3.378		4.148		
						3.374		4.139		
						3.374		4.13		
						3.37		4.148		
						3.378		4.139		
12	60	25	5	10	6	3.38	3.389	4.2	4.203	24.01
						3.398		4.206		
						3.389		4.203		
						3.38		4.2		
						3.398		4.206		
						3.389		4.203		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
13	30	55	0	15	6	3.38	3.387	3.958	3.958	16.85
						3.394		3.946		
						3.387		3.97		
						3.38		3.958		
						3.394		3.946		
						3.387		3.97		
14	40	45	0	15	6	3.612	3.624	4.255	4.258	17.50
						3.645		4.261		
						3.622		4.258		
						3.519		4.255		
						3.684		4.261		
						3.662		4.258		
15	50	35	0	15	6	3.64	3.642	4.28	4.288	17.75
						3.644		4.296		
						3.642		4.288		
						3.64		4.28		
						3.644		4.296		
						3.642		4.288		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
16	60	25	0	15	6	3.775	3.765	4.44	4.446	18.08
						3.742		4.387		
						3.769		4.458		
						3.765		4.51		
						3.755		4.446		
						3.784		4.435		
17	30	53	2	15	6	3.71	3.716	4.42	4.421	18.96
						3.722		4.421		
						3.716		4.422		
						3.71		4.42		
						3.722		4.421		
						3.716		4.42		
18	40	43	2	15	6	3.72	3.722	4.451	4.451	19.58
						3.722		4.449		
						3.724		4.452		
						3.722		4.451		
						3.72		4.452		
						3.724		4.449		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
19	50	33	2	15	6	3.74	3.742	4.5	4.502	20.32
						3.744		4.502		
						3.742		4.502		
						3.74		4.5		
						3.742		4.502		
						3.744		4.504		
20	60	23	2	15	6	3.37	3.374	4.13	4.139	22.67
						3.374		4.148		
						3.378		4.139		
						3.37		4.13		
						3.374		4.148		
						3.378		4.139		
21	30	50	5	15	6	3.15	3.155	3.81	3.817	21.00
						3.16		3.824		
						3.155		3.817		
						3.15		3.81		
						3.16		3.824		
						3.155		3.817		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	**Percentage of Raw materials, %**				**No. of Samples**	**Weight of Dry brick, kg**	**Avg. Weight of Dry brick (M_1), kg**	**Weight of Immersed brick, kg**	**Avg. Weight of Immersed brick (M_2), kg**	**Water absorption, %** $[(M_2-M_1)/M_1]x100$
	IOT	**Sand**	**Perlite**	**Cement**						
22	40	40	5	15	6	3.16	3.167	3.86	3.862	21.96
						3.174		3.864		
						3.167		3.862		
						3.16		3.86		
						3.174		3.864		
						3.167		3.862		
23	50	30	5	15	6	3.183	3.183	3.88	3.888	22.16
						3.18		3.896		
						3.186		3.888		
						3.183		3.88		
						3.18		3.896		
						3.186		3.888		
24	60	20	5	15	6	3.24	3.242	3.98	3.984	22.90
						3.242		3.988		
						3.244		3.984		
						3.24		3.98		
						3.242		3.988		
						3.244		3.984		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
25	30	50	0	20	6	3.382	3.382	3.65	3.68	8.09
						3.382		3.71		
						3.38		3.68		
						3.384		3.67		
						3.381		3.68		
						3.383		3.69		
26	40	40	0	20	6	3.3	3.35	3.627	3.627	8.29
						3.35		3.626		
						3.41		3.628		
						3.36		3.627		
						3.35		3.625		
						3.35		3.629		
27	50	30	0	20	6	3.338	3.339	3.644	3.644	9.12
						3.34		3.642		
						3.339		3.646		
						3.337		3.644		
						3.341		3.642		
						3.339		3.644		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
28	60	20	0	20	6	3.33	3.335	3.654	3.654	9.56
						3.335		3.651		
						3.337		3.657		
						3.338		3.654		
						3.335		3.657		
						3.334		3.651		
29	30	48	2	20	6	3.05	3.051	3.451	3.454	13.21
						3.052		3.458		
						3.051		3.454		
						3.051		3.454		
						3.052		3.451		
						3.049		3.458		
30	40	38	2	20	6	2.774	2.776	3.152	3.152	13.53
						2.778		3.151		
						2.778		3.153		
						2.776		3.152		
						2.774		3.151		
						2.776		3.153		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
31	50	28	2	20	6	2.773	2.774	3.161	3.164	14.06
						2.774		3.168		
						2.775		3.164		
						2.776		3.161		
						2.774		3.168		
						2.774		3.164		
32	60	18	2	20	6	1.907	1.908	2.188	2.187	14.61
						1.907		2.186		
						1.909		2.187		
						1.91		2.188		
						1.908		2.186		
						1.908		2.187		
33	30	45	5	20	6	2.667	2.668	3.045	3.048	14.25
						2.669		3.051		
						2.668		3.048		
						2.665		3.045		
						2.67		3.051		
						2.668		3.048		

Table A – 2 Water absorption of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Weight of Dry brick, kg	Avg. Weight of Dry brick (M_1), kg	Weight of Immersed brick, kg	Avg. Weight of Immersed brick (M_2), kg	Water absorption, % $[(M_2-M_1)/M_1]x100$
	IOT	Sand	Perlite	Cement						
34	40	35	5	20	6	2.741	2.74	3.133	3.137	14.50
						2.74		3.137		
						2.739		3.142		
						2.739		3.133		
						2.741		3.137		
						2.741		3.142		
35	50	25	5	20	6	2.905	2.906	3.333	3.336	14.82
						2.906		3.339		
						2.904		3.336		
						2.908		3.333		
						2.905		3.339		
						2.907		3.336		
36	60	15	5	20	6	3.273	3.276	3.785	3.788	15.64
						3.275		3.792		
						3.28		3.788		
						3.277		3.785		
						3.276		3.792		
						3.276		3.788		

Table A – 3 Compressive strength of bricks of varying percentage of raw materials

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
1	30	60	0	10	6	3.55	3.56
						3.57	
						3.5	
						3.62	
						3.55	
						3.57	
2	40	50	0	10	6	3.81	3.93
						3.94	
						3.86	
						3.91	
						3.96	
						4.1	
3	50	40	0	10	6	3.99	4.12
						4.32	
						3.99	
						3.99	
						4.32	
						4.12	
4	60	30	0	10	6	5.02	4.76
						5.02	
						4.25	
						4.22	
						5.02	
						5.05	

Table A – 3 Compressive strength of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
5	30	58	2	10	6	2.62	2.62
						2.62	
						2.62	
						2.59	
						2.65	
						2.62	
6	40	48	2	10	6	2.6	2.69
						2.78	
						2.69	
						2.6	
						2.78	
						2.69	
7	50	38	2	10	6	2.7	2.75
						2.8	
						2.75	
						2.75	
						2.8	
						2.7	
8	60	28	2	10	6	3.09	2.83
						2.7	
						2.7	
						2.8	
						2.75	
						2.94	

Table A – 3 Compressive strength of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
9	30	55	5	10	6	1.3	1.34
						1.38	
						1.26	
						1.42	
						1.32	
						1.36	
10	40	45	5	10	6	1.54	1.41
						1.54	
						1.15	
						1.41	
						1.41	
						1.41	
11	50	35	5	10	6	1.54	1.54
						1.54	
						1.54	
						1.54	
						1.61	
						1.47	
12	60	25	5	10	6	1.54	1.67
						1.54	
						1.93	
						1.67	
						1.67	
						1.67	

Table A – 3 Compressive strength of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
13	30	55	0	15	6	5.2	5.29
						5.38	
						5.29	
						5.29	
						5.20	
						5.38	
14	40	45	0	15	6	6.00	6.10
						6.20	
						6.10	
						6.00	
						6.10	
						6.20	
15	50	35	0	15	6	6.90	6.95
						7.00	
						6.95	
						6.90	
						7.00	
						6.95	
16	60	25	0	15	6	7.00	7.10
						7.20	
						7.10	
						7.19	
						7.01	
						7.10	
17	30	53	2	15	6	3.18	3.18
						3.18	
						3.05	
						3.05	
						3.31	
						3.31	

Table A – 3 Compressive strength of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
18	40	43	2	15	6	3.28	3.28
						3.28	
						3.28	
						3.33	
						3.12	
						3.39	
19	50	33	2	15	6	3.3	3.30
						3.25	
						3.25	
						3.3	
						3.35	
						3.35	
20	60	23	2	15	6	3.55	3.56
						3.57	
						3.5	
						3.62	
						3.55	
						3.57	
21	30	50	5	15	6	1.93	1.93
						1.93	
						1.93	
						1.83	
						1.88	
						2.08	
22	40	40	5	15	6	1.54	1.93
						2.31	
						1.93	
						1.93	
						1.93	
						1.93	
23	50	30	5	15	6	2.32	2.06
						1.93	
						1.93	
						2.06	
						2.06	
						2.06	

Table A – 3 Compressive strength of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
24	60	20	5	15	6	2.54	2.41
						2.54	
						2.15	
						2.41	
						2.41	
						2.41	
25	30	50	0	20	6	8.01	8.16
						8.11	
						8.32	
						8.16	
						8.24	
						8.12	
26	40	40	0	20	6	9.54	9.62
						9.75	
						9.66	
						9.62	
						9.54	
						9.61	
27	50	30	0	20	6	10.45	10.45
						10.87	
						10.03	
						10.38	
						10.47	
						10.5	
28	60	20	0	20	6	11.19	11.19
						11.1	
						11.28	
						11.19	
						11.1	
						11.28	
29	30	48	2	20	6	4.35	4.30
						4.3	
						4.3	
						4.25	
						4.25	
						4.35	

Table A – 3 Compressive strength of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
30	40	38	2	20	6	4.45	4.45
						4.25	
						4.65	
						4.25	
						4.65	
						4.45	
31	50	28	2	20	6	4.58	4.58
						4.58	
						4.58	
						4.55	
						4.61	
						4.58	
32	60	18	2	20	6	4.7	4.72
						4.74	
						4.72	
						4.7	
						4.72	
						4.74	
33	30	45	5	20	6	3.65	3.68
						3.71	
						3.68	
						3.68	
						3.65	
						3.71	
34	40	35	5	20	6	3.67	3.79
						3.66	
						4.24	
						3.59	
						3.79	
						3.79	

Table A – 3 Compressive strength of bricks of varying percentage of raw materials (continued…)

Sl. No	Percentage of Raw materials, %				No. of Samples	Compressive Strength, MPa	Avg. Compressive Strength, MPa
	IOT	Sand	Perlite	Cement			
35	50	25	5	20	6	3.89	3.89
						3.8	
						3.98	
						3.89	
						3.8	
						3.98	
36	60	15	5	20	6	4	4.08
						4.16	
						4.08	
						4.08	
						4.16	
						4	

Table A – 4 Thermal conductivity of bricks of varying percentage of raw materials

Sl. No.	Percentage of Raw materials, %				No. of Sample	Trial	Thermal conductivity, W/mk	Avg. Thermal conductivity, W/mk
	IOT	Sand	Perlite	Cement				
						1	1.490	
1.	30	60			16	2	1.491	1.491
						3	1.491	
						1	1.494	
2.	40	50			16	2	1.495	1.495
			0	10		3	1.495	
						1	1.497	
3.	50	40			16	2	1.497	1.497
						3	1.497	
						1	1.498	
4.	60	30			16	2	1.499	1.499
						3	1.499	
						1	1.221	
5.	30	58			16	2	1.220	1.220
						3	1.220	
						1	1.236	
6.	40	48			16	2	1.236	1.236
			2	10		3	1.236	
						1	1.258	
7.	50	38			16	2	1.258	1.259
						3	1.259	
						1	1.291	
8.	60	28			16	2	1.290	1.290
						3	1.290	
						1	0.900	
9.	30	55			16	2	0.901	0.901
						3	0.901	
						1	0.903	
10.	40	45	5	10	16	2	0.902	0.903
						3	0.903	
						1	0.911	
11.	50	35			16	2	0.912	0.912
						3	0.912	

Table A – 4 Thermal conductivity of bricks of varying percentage of raw materials (continued…)

Sl. No.	Percentage of Raw materials, %				No. of Sample	Trial	Thermal conductivity, W/mk	Avg. Thermal conductivity, W/mk
	IOT	Sand	Perlite	Cement				
12.	60	25			16	1	0.923	0.924
						2	0.924	
						3	0.924	
13.	30	55	0	15	16	1	1.491	1.492
						2	1.492	
						3	1.492	
14.	40	45			16	1	1.498	1.497
						2	1.497	
						3	1.497	
15.	50	35			16	1	1.514	1.514
						2	1.514	
						3	1.514	
16.	60	25			16	1	1.521	1.521
						2	1.521	
						3	1.521	
17.	30	53	2	15	16	1	1.270	1.271
						2	1.271	
						3	1.271	
18.	40	43			16	1	1.278	1.278
						2	1.278	
						3	1.278	
19.	50	33			16	1	1.290	1.291
						2	1.291	
						3	1.291	
20.	60	23			16	1	1.311	1.310
						2	1.310	
						3	1.310	
21.	30	50	5	15	16	1	0.902	0.903
						2	0.903	
						3	0.903	
22.	40	40			16	1	0.903	0.904
						2	0.904	
						3	0.904	

Table A – 4 Thermal conductivity of bricks of varying percentage of raw materials (continued…)

Sl. No.	Percentage of Raw materials, %				No. of Sample	Trial	Thermal conductivity, W/mk	Avg. Thermal conductivity, W/mk
	IOT	Sand	Perlite	Cement				
23	50	30			16	1	0.938	0.939
						2	0.937	
						3	0.939	
24.	60	20			16	1	0.938	0.939
						2	0.937	
						3	0.939	
25.	30	50	0	20	16	1	1.778	1.778
						2	1.778	
						3	1.778	
26.	40	40			16	1	1.781	1.780
						2	1.780	
						3	1.780	
27.	50	30			16	1	1.781	1.782
						2	1.781	
						3	1.782	
28.	60	20			16	1	1.784	1.784
						2	1.783	
						3	1.784	
29.	30	48	2	20	16	1	1.285	1.285
						2	1.285	
						3	1.285	
30.	40	38			16	1	1.289	1.289
						2	1.289	
						3	1.289	
31.	50	28			16	1	1.292	1.292
						2	1.292	
						3	1.292	
32.	60	18			16	1	1.312	1.312
						2	1.311	
						3	1.312	
33.	30	45	5	20	16	1	0.904	0.905
						2	0.905	
						3	0.905	

Table A – 4 Thermal conductivity of bricks of varying percentage of raw materials (continued…)

Sl. No.	Percentage of Raw materials, %				No. of Sample	Trial	Thermal conductivity, W/mk	Avg. Thermal conductivity, W/mk
	IOT	Sand	Perlite	Cement				
34.	40	35			16	1	0.906	0.906
						2	0.906	
						3	0.906	
35.	50	25			16	1	0.921	0.920
						2	0.920	
						3	0.920	
36.	60	15			16	1	0.940	0.941
						2	0.941	
						3	0.941	

APPENDIX B

Table B – 1: Temperature measurement before plastering in forenoon of walls, roof and room of model rooms

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
29^{0}C	NW	25.50	25.50	25.00	22.00	21.50	21.50	14-06-2019	10:07 AM	29.50	29.50	29.00	26.50	26.00	25.00	14-06-2019	10:00 AM
	EW	26.00	26.00	25.50	22.50	21.50	21.00			30.00	30.00	29.50	27.00	26.50	26.00		
	SW	25.50	25.50	25.00	21.50	21.00	20.50			29.50	29.00	28.00	26.00	25.50	25.00		
	WW	25.00	24.50	24.00	21.00	20.50	20.00			29.00	28.50	28.00	25.50	25.00	24.50		
	Roof				b/w 29.50 & 31.00					Roof			b/w 30.50 & 32.00				
	Room Temperature				25.00					Room Temperature			27.00				
27^{0}C	NW	26.00	25.00	25.00	24.50	24.50	24.50	25-06-2019	10:30 AM	30.00	30.00	29.50	26.50	26.00	26.50	25-06-2019	10:20 AM
	EW	27.00	27.00	26.50	24.00	24.00	24.00			28.50	29.00	29.00	25.00	25.50	25.00		
	SW	25.50	25.00	25.50	23.00	23.00	23.00			29.00	28.50	29.00	25.50	25.50	25.50		
	WW	25.00	24.50	25.50	23.00	22.50	22.50			28.50	28.50	28.50	25.00	25.00	25.50		
	Roof				b/w 33.00 &38.00					Roof			b/w 34.00 & 37.00				
	Room Temperature				23.00					Room Temperature			25.00				

Table B – 1: Temperature measurement before plastering in forenoon of walls, roof and room of model rooms (continued…)

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^0C			Inside Wall, ^0C					Outside Wall, ^0C			Inside Wall, ^0C				
		T	M	B	T	M	B			T	M	B	T	M	B		
29.00 ^0C	NW	25.50	25.00	25.00	24.00	24.00	24.50	31-07-2019	11:33 AM	29.00	28.00	28.00	26.50	26.50	26.50	31-07-2019	11:28 AM
	EW	25.00	25.50	25.00	24.00	24.00	24.00			28.00	28.00	28.00	26.00	26.50	26.50		
	SW	25.00	25.00	25.50	24.50	24.00	24.00			28.50	28.00	28.00	26.50	26.00	26.00		
	WW	25.50	25.50	25.50	24.00	24.00	24.00			28.00	28.00	28.00	26.00	26.50	26.00		
	Roof				b/w 33.00 & 36.50					Roof			b/w 38.50 & 42.50				
	Room Temperature				23.50					Room Temperature			25.00				
29^0C	NW	25.50	25.00	25.00	24.50	24.00	24.00	27-07-2019	11:34 AM	29.00	29.00	28.50	27.00	26.50	26.50	27-07-2019	11:22 AM
	EW	25.50	25.50	25.50	24.50	24.50	24.50			29.00	28.50	28.50	27.00	26.50	27.00		
	SW	25.00	25.50	25.50	24.50	24.50	24.00			28.50	28.50	28.50	26.50	27.00	26.50		
	WW	25.50	25.00	25.50	24.00	24.00	24.50			28.50	28.50	28.50	27.00	27.00	26.50		
	Roof				b/w 33.00 and 37.00					Roof			b/w 35.50 and 38.50				
	Room Temperature				23.00					Room Temperature			26.00				

Table B – 1: Temperature measurement before plastering in forenoon of walls, roof and room of model rooms (continued…)

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
27^{0}C	NW	22.50	22.00	23.00	21.50	20.50	19.50	15-06-2019	11:45 AM	30.50	30.00	30.50	26.00	26.50	26.00	15-06-2019	11:30 AM
	EW	24.00	28.00	30.50	23.00	23.00	22.00			29.50	31.00	31.50	26.50	26.00	26.00		
	SW	23.00	23.00	22.00	22.50	21.00	20.50			27.50	26.00	24.00	24.50	24.50	24.00		
	WW	24.50	25.00	24.00	22.50	22.00	21.00			27.50	25.00	23.50	23.50	23.00	23.00		
	Roof				b/w 38.00 & 42.00					Roof			b/w 36.00 & 39.00				
	Room Temperature				21.50					Room Temperature			23.00				
31^{0}C	NW	24.50	24.00	24.00	23.50	23.50	23.50	24-06-2019	11:55 AM	30.50	30.50	30.50	28.50	28.50	28.00	24-06-2019	11:40 AM
	EW	25.00	25.00	25.00	24.00	24.50	24.50			31.50	31.50	31.50	28.50	28.50	28.00		
	SW	24.50	24.50	24.50	23.00	23.50	23.50			30.50	29.50	29.50	28.00	28.00	28.00		
	WW	24.50	24.00	24.50	23.50	23.50	23.00			29.50	29.50	29.50	28.50	28.00	28.50		
	Roof				b/w 36.50 & 42.00					Roof			b/w 39.50 & 44.50				
	Room Temperature				24.50					Room Temperature			26.00				

Table B – 2: Temperature measurement before plastering in midday at walls, roof and room of model rooms

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
32^{0}C	NW	29.50	27.50	29.00	28.00	26.00	25.00	16-06-2019	12:17 PM	32.50	32.50	32.50	29.50	27.00	26.50	16-06-2019	12:00 PM
	EW	30.50	34.00	35.00	29.00	29.00	28.00			32.50	33.50	36.00	29.50	27.00	26.50		
	SW	30.00	29.50	27.00	28.00	26.00	25.00			32.50	28.50	26.50	29.50	26.00	25.50		
	WW	31.50	30.50	28.50	27.50	26.50	25.50			31.50	28.50	27.50	28.50	26.50	25.50		
	Roof				b/w 43.50 & 50.00					Roof			b/w 44.50 & 49.00				
	Room Temperature				24.50					Room Temperature			26.00				
33^{0}C	NW	25.50	26.50	26.50	24.50	24.00	24.50	07-06-2019	12.28 PM	34.00	33.50	34.50	31.00	31.50	31.50	07-06-2019	12:15 PM
	EW	26.50	26.50	26.50	25.00	25.50	25.00			34.00	33.50	33.50	31.00	31.00	31.50		
	SW	25.00	25.50	25.50	23.50	23.00	23.00			34.50	33.50	32.50	31.50	31.00	30.50		
	WW	24.50	25.00	25.00	23.00	23.00	23.50			32.00	32.50	32.00	30.50	30.50	30.00		
	Roof				b/w 35.50 & 44.50					Roof			b/w 40.00 & 44.50				
	Room Temperature				23.00					Room Temperature			29.00				

Table B – 2: Temperature measurement before plastering in midday at walls, roof and room of model rooms (continued…)

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
31^{0}C	NW	27.00	25.50	26.00	26.50	24.50	23.00	17-06-2019	12:40 PM	33.50	33.00	33.50	29.50	29.00	29.50	17-06-2019	12:30 PM
	EW	28.50	31.00	32.00	27.50	26.50	26.00			32.00	33.00	33.50	29.50	29.50	29.50		
	SW	27.50	27.50	26.00	26.50	24.50	23.00			32.50	30.50	30.50	29.00	29.00	29.00		
	WW	28.00	28.50	26.50	26.50	24.50	23.50			31.50	31.50	31.50	27.50	28.00	28.50		
	Roof				b/w 41.00 & 48.50					Roof			b/w 43.50 & 47.00				
	Room Temperature				25.00					Room Temperature			27.00				
31^{0}C	NW	25.50	25.50	25.00	24.50	23.50	23.50	18-06-2019	12:48 PM	29.00	29.00	29.50	26.50	26.00	26.50	18-06-2019	12:35 PM
	EW	26.50	28.50	29.00	25.00	25.50	25.00			30.00	30.00	30.00	27.00	27.00	27.00		
	SW	25.00	25.50	25.50	24.50	24.00	24.50			28.50	28.50	28.00	26.00	27.50	27.00		
	WW	26.00	27.00	25.50	25.00	25.50	24.50			29.50	28.50	28.00	26.00	26.00	26.50		
	Roof				b/w 41.00 & 43.00					Roof			b/w 42.00 & 48.00				
	Room Temperature				24.00					Room Temperature			25.00				

Table B – 2: Temperature measurement before plastering in midday at walls, roof and room of model rooms (continued…)

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^0C			Inside Wall, ^0C					Outside Wall, ^0C			Inside Wall, ^0C				
		T	M	B	T	M	B			T	M	B	T	M	B		
29^0C	NW	22.50	21.50	21.00	21.00	20.00	20.00	27-06-2019	1:57 PM	26.50	26.50	26.00	22.50	21.50	21.00	27-06-2019	1:50 PM
	EW	22.00	22.50	21.00	21.50	20.50	20.50			26.00	26.00	25.50	22.50	22.00	21.50		
	SW	23.00	22.50	21.50	21.50	20.50	20.00			26.00	25.50	24.50	22.50	21.50	21.00		
	WW	23.50	24.00	23.00	21.50	20.50	20.50			26.50	25.50	25.50	22.00	21.50	21.00		
	Roof				b/w 29.00 & 32.00					Roof			b/w 30.50 & 33.00				
	Room Temperature				19.00					Room Temperature			20.00				
31^0C	NW	30.50	28.50	28.00	29.50	27.00	25.50	17-06-2019	2:52 PM	32.50	32.00	32.50	30.50	30.50	30.50	17-06-2019	2:40 PM
	EW	29.00	30.50	30.00	28.50	28.50	28.00			32.50	32.00	32.00	30.00	30.50	29.50		
	SW	30.50	30.00	30.50	30.00	29.50	29.00			32.00	32.00	32.50	30.50	29.50	20.00		
	WW	30.50	30.50	30.50	29.50	28.00	28.50			31.50	31.50	31.00	29.00	30.00	29.50		
	Roof				b/w 38.00 & 43.50					Roof			b/w 40.00 & 45.00				
	Room Temperature				26.50					Room Temperature			28.00				

Table B – 3: Temperature measurement before plastering in evening at walls, roof and room of model rooms

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^0C			Inside Wall, ^0C					Outside Wall, ^0C			Inside Wall, ^0C				
		T	M	B	T	M	B			T	M	B	T	M	B		
32^0C	NW	30.00	30.00	30.00	28.50	28.50	28.00	07-06-2019	4:10 PM	33.50	33.50	32.00	31.00	30.50	30.00	07-06-2019	3:45 PM
	EW	29.00	28.50	29.00	27.00	27.50	27.00			32.50	32.00	30.50	30.50	30.00	30.00		
	SW	30.50	30.00	30.00	28.50	28.50	28.50			33.00	33.50	32.00	31.50	31.00	31.50		
	WW	31.00	31.00	31.50	29.00	28.00	28.50			33.50	33.50	33.50	31.00	31.00	31.50		
	Roof				b/w 35.50 & 45.50					Roof			b/w 39.00 & 45.00				
	Room Temperature				26.00					Room Temperature			28.00				
30^0C	NW	28.50	28.50	28.00	27.00	27.00	27.50	01-07-2019	4:15 PM	32.50	32.00	32.00	29.00	29.00	29.50	01-07-2019	4:00 PM
	EW	28.00	28.00	28.00	27.50	27.00	27.00			32.00	32.50	32.00	29.00	29.50	29.50		
	SW	28.50	28.50	28.00	27.50	27.00	27.00			32.50	32.50	32.00	29.00	29.50	29.00		
	WW	28.00	28.00	28.00	27.50	27.00	27.50			32.00	32.00	32.00	29.50	29.50	29.00		
	Roof				b/w 39.00 & 43.50					Roof			b/w 38.00 & 43.00				
	Room Temperature				25.00					Room Temperature			27.00				

Table B – 3: Temperature measurement before plastering in evening at walls, roof and room of model rooms (continued…)

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^0C			Inside Wall, ^0C					Outside Wall, ^0C			Inside Wall, ^0C				
		T	M	B	T	M	B			T	M	B	T	M	B		
30^0C	NW	28.50	29.00	27.50	25.50	24.50	23.50	29-06-2019	5:08 PM	32.50	31.50	31.00	28.00	26.50	26.00	29-06-2019	5:00 PM
	EW	28.50	28.00	28.50	26.00	25.00	24.00			32.00	32.00	31.50	28.00	26.50	26.00		
	SW	29.00	28.50	27.00	25.00	24.50	23.00			32.50	31.50	31.50	27.50	26.00	25.50		
	WW	28.00	27.50	25.50	25.50	24.50	23.00			30.00	31.00	30.00	27.00	26.00	25.00		
	Roof				b/w 35.50 & 39.00					Roof			b/w 36.50 & 39.00				
	Room Temperature				27.50					Room Temperature			29.00				
28^0C	NW	27.50	27.50	27.00	25.50	26.50	26.00	15-06-2019	6:05 PM	30.50	30.50	29.50	29.00	29.50	28.00	15-06-2019	5:55 PM
	EW	26.00	26.50	26.50	25.00	26.00	25.00			30.00	29.50	28.00	29.00	29.00	27.50		
	SW	27.50	27.50	26.50	26.00	26.00	26.00			31.00	30.00	27.50	30.50	29.50	27.00		
	WW	27.50	27.50	27.00	26.00	26.50	26.00			31.50	30.50	30.00	31.00	30.00	29.00		
	Roof				b/w 28.50 & 29.00					Roof			b/w 28.50 & 30.50				
	Room Temperature				28.00					Room Temperature			29.50				

Table B – 3: Temperature measurement before plastering in evening at walls, roof and room of model rooms (continued…)

Ambient Temperature		IOT Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
29^{0}C	NW	25.00	24.50	24.50	23.00	23.50	23.50	30-06-2019	6:09 PM	30.50	30.50	30.00	27.00	27.50	27.00	30-06-2019	6:00 PM
	EW	25.00	25.50	25.50	23.50	23.00	23.00			29.50	29.50	30.50	27.50	27.50	27.50		
	SW	25.00	25.00	24.50	23.00	23.00	23.50			30.00	29.50	30.00	27.50	27.50	27.50		
	WW	24.50	24.50	24.50	23.00	23.50	23.50			30.00	30.00	30.00	27.50	27.00	27.00		
	Roof				b/w 33.50 & 38.50					Roof			b/w 33.00 & 40.50				
	Room Temperature				22.00					Room Temperature			25.00				
29.00 ^{0}C	NW	23.50	23.00	23.50	22.00	22.50	22.00	31-07-2019	6:35 PM	30.00	30.00	30.00	28.00	27.50	27.50	31-07-2019	6:30 PM
	EW	23.50	23.50	23.00	22.00	22.00	22.00			30.50	30.00	30.50	28.00	28.00	28.00		
	SW	23.00	23.50	23.50	22.50	22.50	22.00			30.50	30.50	30.50	28.00	27.50	27.50		
	WW	23.50	23.50	23.00	22.50	22.00	22.50			30.50	30.00	30.00	28.00	28.00	27.50		
	Roof				b/w 38.50 & 44.00					Roof			b/w 43.50 & 47.50				
	Room Temperature				22.00					Room Temperature			26.00				

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre)
B - Bottom (Temperature measured 1foot above the bottom)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

APPENDIX C

Table C – 1: Temperature measurement after plastering in forenoon at walls, roof and room of model rooms

Ambient Temperature		IOT – Perlite Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
29^{0}C	NW	25.50	25.50	25.00	22.00	21.50	21.50	14-06-2019	10:07 am	29.50	29.50	29.00	26.50	26.00	25.00	14-06-2019	10:00 am
	EW	26.00	26.00	25.50	22.50	21.50	21.00			30.00	30.00	29.50	27.00	26.50	26.00		
	SW	25.50	25.50	25.00	21.50	21.00	20.50			29.50	29.00	28.00	26.00	25.50	25.00		
	WW	25.00	24.50	24.00	21.00	20.50	20.00			29.00	28.50	28.00	25.50	25.00	24.50		
	Roof				b/w 29.50 & 31.00					Roof			b/w 30.50 & 32.00				
	Room Temperature				25.00^{0}C					Room Temperature			27.50^{0}C				
35^{0}C	NW	27.00	26.50	25.00	19.50	17.00	16.00	07-10-2019	10:35 am	35.50	35.00	32.50	30.00	27.00	25.00	07-10-2019	10:30 am
	EW	25.00	25.50	24.50	20.00	19.50	19.00			29.50	29.00	27.00	27.00	26.00	25.50		
	SW	32.50	36.00	37.00	27.50	26.50	25.00			33.50	37.50	38.00	30.00	29.50	28.00		
	WW	31.00	30.50	29.50	25.00	22.50	20.00			32.00	32.00	31.50	28.00	25.50	23.50		
	Roof				b/w 44.00 & 48.00					Roof			b/w 43.50 & 48.50				
	Room Temperature				32.00^{0}C					Room Temperature			34.50^{0}C				

Table C – 1: Temperature measurement after plastering in forenoon at walls, roof and room of model rooms (continued…)

Ambient Temperature		IOT – Perlite Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
32.50 ^{0}C	NW	27.00	25.00	23.50	24.50	21.50	21.00	14-06-2019	9:45 am	23.50	23.50	22.50	23.50	21.50	21.50	14-06-2019	9:40 am
	EW	25.00	26.00	26.00	24.50	22.50	21.50			22.50	23.50	24.50	24.00	22.50	22.00		
	SW	25.50	26.50	26.50	24.00	22.00	21.50			25.00	26.50	26.50	23.50	22.50	22.50		
	WW	28.00	26.50	23.50	24.00	22.00	21.00			27.00	26.00	24.50	24.00	23.00	22.00		
	Roof				b/w 40.00 & 43.50					Roof			b/w 38.00 & 43.00				
	Room Temperature				30.00^{0}C					Room Temperature			32.50^{0}C				

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre)
B - Bottom (Temperature measured 1foot above the bottom)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

Table C – 2: Temperature measurement after plastering in midday at walls, roof and room of model rooms

Ambient Temperature		IOT – Perlite Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
30^0C	NW	28.50	29.00	27.50	25.50	24.50	23.50	29-06-2019	12:08 pm	32.50	31.50	31.00	28.00	26.50	26.00	29-06-2019	12:00 pm
	EW	28.50	28.00	28.50	26.00	25.00	24.00			32.00	32.00	31.50	28.00	26.50	26.00		
	SW	29.00	28.50	27.00	25.00	24.50	23.00			32.50	31.50	31.50	27.50	26.00	25.50		
	WW	28.00	27.50	25.50	25.50	24.50	23.00			30.00	31.00	30.00	27.00	26.00	25.00		
	Roof				b/w 38.00 & 43.50					Roof			b/w 36.50&39.00				
	Room Temperature				27.50^0C					Room Temperature			29.00^0C				
35^0C	NW	32.50	31.00	28.00	28.50	27.00	25.00	27-09-2019	12:52 pm	33.50	32.00	31.50	30.50	30.50	29.50	27-09-2019	12:45 pm
	EW	30.00	29.00	28.00	27.50	26.00	25.00			30.50	29.50	29.00	29.50	28.00	28.00		
	SW	32.50	33.00	33.50	30.00	29.50	28.00			33.00	33.50	34.50	32.00	31.00	30.50		
	WW	30.50	31.00	31.50	26.00	25.50	24.50			31.50	31.50	32.50	29.50	29.00	28.00		
	Roof				b/w 43.50 & 49.00					Roof			b/w 44.50 & 49.50				
	Room Temperature				31.50^0C					Room Temperature			34.00^0C				

Table C – 2: Temperature measurement after plastering in midday at walls, roof and room of model rooms (continued….)

Ambient Temperature		IOT – Perlite Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
32^{0}C	NW	22.50	22.00	21.00	32.50	20.00	19.00	30-09-2019	1:07 pm	21.50	20.00	18.50	20.00	17.00	16.50	30-09-2019	1:00 pm
	EW	26.00	26.50	26.00	27.50	26.00	24.00			22.50	22.50	21.00	24.00	22.50	22.00		
	SW	29.50	31.50	32.50	29.00	27.00	27.00			30.50	32.50	33.00	29.00	28.00	28.00		
	WW	31.00	32.50	33.50	29.00	27.50	26.50			32.00	32.50	32.00	29.50	28.00	27.00		
	Roof				b/w 39.00 & 41.00					Roof			b/w 39.00 & 40.00				
	Room Temperature				32.50					Room Temperature			35.00				
34.50 ^{0}C	NW	21.50	21.00	19.00	19.00	17.50	15.00	01-10-2019	12:35 pm	22.50	22.00	20.50	21.00	20.00	18.50	01-10-2019	12:30 pm
	EW	22.50	23.50	21.00	20.50	20.00	17.00			23.50	24.00	22.00	23.00	22.50	20.00		
	SW	29.50	31.50	32.00	26.50	25.00	25.00			30.50	33.00	33.00	29.00	28.50	28.00		
	WW	27.00	26.50	26.00	25.00	23.50	22.50			28.50	28.00	27.00	26.50	25.50	24.00		
	Roof				b/w 43.50 & 49.00					Roof			b/w 42.50 & 48.00				
	Room Temperature				32.50^{0}C					Room Temperature			35.00^{0}C				

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre)
B - Bottom (Temperature measured 1foot above the bottom)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

Table C – 3: Temperature measurement after plastering in evening at walls, roof and room of model rooms

Ambient Temperature		IOT – Perlite Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^0C			Inside Wall, ^0C					Outside Wall, ^0C			Inside Wall, ^0C				
		T	M	B	T	M	B			T	M	B	T	M	B		
28^0C	NW	27.50	27.50	27.00	25.50	26.50	26.00	15-06-2019	6:05 pm	30.50	30.50	29.50	29.00	29.50	28.00	15-06-2019	5:55 pm
	EW	26.00	26.50	26.50	25.00	26.00	25.00			30.00	29.50	28.00	29.00	29.00	27.50		
	SW	27.50	27.50	26.50	26.00	26.00	26.00			31.00	30.00	27.50	30.50	29.50	27.00		
	WW	27.50	27.50	27.00	26.00	26.50	26.00			31.50	30.50	30.00	31.00	30.00	29.00		
	Roof				b/w 28.00 & 29.00					Roof			b/w 28.50 & 30.50				
	Room Temperature				26.50					Room Temperature			28.00				
35^0C	NW	30.00	29.50	28.00	28.50	27.00	25.50	30-09-2019	4:15 pm	30.50	30.00	29.00	29.50	28.50	27.00	30-09-2019	4:10 pm
	EW	30.50	29.00	27.50	27.00	25.50	25.00			30.00	29.00	28.00	28.00	27.50	27.00		
	SW	31.50	32.50	33.00	27.50	29.50	28.00			32.50	33.00	33.50	30.50	31.00	30.50		
	WW	31.00	32.00	34.00	27.50	27.00	25.00			31.50	33.00	35.00	29.50	29.00	28.00		
	Roof				b/w 40.00 & 46.00					Roof			b/w 41.00 & 47.00				
	Room Temperature				32.00					Room Temperature			34.50				

Table C – 3: Temperature measurement after plastering in evening at walls, roof and room of model rooms (continued….)

Ambient Temperature		IOT – Perlite Bricks						Date	Time	Ordinary Bricks						Date	Time
		Outside Wall, ^{0}C			Inside Wall, ^{0}C					Outside Wall, ^{0}C			Inside Wall, ^{0}C				
		T	M	B	T	M	B			T	M	B	T	M	B		
34.50 ^{0}C	NW	28.00	27.00	25.50	28.00	26.00	24.00	02-11-2019	4:17 pm	29.50	28.50	27.50	29.50	27.00	25.50	02-11-2019	4:15 pm
	EW	26.50	25.00	22.50	27.00	25.00	23.00			28.00	27.50	25.00	28.50	26.50	24.50		
	SW	20.50	24.50	27.00	24.50	24.00	24.50			24.50	27.00	27.50	27.00	26.00	25.50		
	WW	44.50	47.50	42.50	28.00	29.00	27.50			38.50	46.00	45.50	28.50	31.00	29.50		
	Roof				b/w 32.00 & 34.00					Roof			b/w 30.50 & 34.50				
	Room Temperature				31.50^{0}C					Room Temperature			33.50^{0}C				

T - Top (Temperature measured 1 foot below the top)
M - Middle (Temperature measured at centre)
B - Bottom (Temperature measured 1foot above the bottom)

NW - North Wall
EW - East Wall
SW - South Wall
WW - West Wall

LIST OF PUBLICATIONS

LIST OF PUBLICATIONS BASED ON PH.D. RESEARCH WORK

1. **Shubhananda Rao P**., Gayana B. C., and Ram Chandar K., (2019), "Use of iron ore mine tailings in infrastructure projects" *International Journal Mining and Mineral Engineering,* Vol. 10, No. 01, 51-59. **(Scopus)**

2. **Shubhananda Rao P.** and Ram Chandar K., (2020), "Development of Energy Efficient Organic Bricks in Construction using IOT and Perlite: A Pilot Scale Study" *International Journal of Sustainable Engineering.(***Scopus).** https://doi.org/10.1080/19397038.2020.1838662

3. **Shubhananda Rao P**., Gayana B. C., and Ram Chandar K., (2020), "Experimental study on iron ore tailings as aggregate in development of bricks and concrete" *International Conference on Advances in Material Science.* **(Scopus).**

4. **Shubhananda Rao P.** and Ram Chandar K., "Development of Green Building Materials Utilizing Mine Waste and Perlite" *Global Conference on Advanced Smart and Sustainable Technologies in Engineering MITE, Moodabidri (GCASTE 2020), 29-30 Jan-2020.*

BIO-DATA

BIODATA

1.	**Name**	:	Shubhananda Rao P
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M.Tech (Construction Technology and Management)	NITK, Surathkal	2014
B.Tech in Civil (Construction Management)	IGNOU	2010

INTERNATIONAL CONFERENCE

- **Shubhananda Rao P** and Ram Chandar K (2015). "Engineering properties of laterites and utilization of lateritic powder and quarry dust in building blocks". 6th International Engineering Symposium (IES-2015), Kumamoto University, Japan, March 5.

- **Shubhananda Rao P** and Ram Chandar K (2020). "Development of green building materials utilizing mine wastes and perlite." Global Conference on Advanced Smart & Sustainable Technologies in Engineering (GCASSTE-2020), Mangalore Institute of Technology & Engineering, Moodabidri, India, January 30-31.

- **Shubhananda Rao P**, Gayana B C and Ram Chandar K (2020). "Experimental study on iron ore tailings as aggregate in development of bricks and concrete." International Conference on Advances in Material Science (ICAMS-2020), Dr. VithalraoVikhePatil College of Engineering, Ahmednagar, India, October 3.

WORKSHOPS

- Workshops on "Recent Trends in Environment, Health and Safety Management in Mining and other Core Industries" organized by the Department of Mining Engineering, National Institute of Technology, Surathkal, during January 27-28, 2017.

PROFESSIONALMEMBERSHIP

- Fellow Member of Association of Consulting Civil Engineers (INDIA) – Membership No. 1711- I

- Member of Council of Engineers & Valuers (Regd.) – Membership No. CEV/SM/773

- Professional Engineer of Engineering Council of India (ECI) – Registration No. PE/0065/16

- Associate Member of the Institution of Engineers (India) – Membership No. AM155851-2

- Member of the Indian Institution of Valuers, Registered Valuers Organization, recognized by Insolvency and Bankruptcy Board of India (Membership No: IIV-RVO/OM/160/2018) of asset class Land & Buildings.

- Registered Valuer of Insolvency and Bankruptcy Board of India (IBBI) – Registration No. IBBI/RV/04/2019/10797