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ENVIRONMENTAL PRODUCT DECLARATION – A TOOL FOR BUILDING MATERIAL SELECTION TO MINIMIZE ITS ENVIRONMENTAL IMPACT

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ABSTRACT

With the growing global environmental concerns, environmental architects and planners are conscious about the environmental impact of building material throughout the life cycle of building. This necessitates the requirement of tools and information that will aid them in decision making process to address environmental impacts of building materials.

The systematic selection of building material is highly significant considering its environmental impact in its life cycle. The Environmental Product Declaration - EPD is a standardized way of quantifying the environmental impact of building material. This research paper uses EPD as a tool for a comparative analysis of the materials from the available range of the products for the selection process to reduce the environmental impact of built form. The impact assessment is carried out for different impact categories like Global warming, Ozone depletion, Acidification of soil and water, Eutrophication, Photochemical ozone creation, Depletion of abiotic resources (elements) and Depletion of abiotic resources (fossile).

The use of masonry blocks in building envelop and partition walls are still significant in current residential buildings in India and its consumption is as high as 11% of the total consumption of building materials. Therefore, it is essential to evaluate the environmental impact of masonry blocks so that it helps architects in the selection process of masonry materials. In this research paper, the environmental impact of concrete masonry block, autoclaved aerated concrete - AAC block, pre-cast concrete block and fired clay brick is compared to take decision for material selection.

The literature review is done to study different environmental impact of concrete masonry block, AAC block, pre-cast concrete block and fired clay brick. Finally, comparative analysis of environmental impacts of these four masonry materials will be analyzed. The results will help in the selection of materials to reduce its environmental impact throughout its life cycle.

Keywords: Documentation, EPD, Impact category, Masonry material

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I. INTRODUCTION

A wide range of building materials are used in construction of infrastructure and building projects. The manufacturing and construction process and huge usage of building materials make a significant environmental impact internally, locally, regionally and globally. To reduce the environmental impacts of building materials for the whole building over its entire life cycle is the necessity of construction industry.

Construction industry is responsible for enormous natural resources consumption and emission of various waste materials in environment. The building industry needs to develop environment friendly strategies in their working process and material selection.

Various tools have been developed that can aid environmental architects and planners in selecting building materials to address the issue of environmental impact of building materials. This leads to the requirement of well documented information about the environmental load of product from cradle to grave.[1]

This is one of the challenging tasks to deliver information to make adequate holistic decisions considering the whole life cycle of building.

Decisions in sustainable building integrate a number of strategies during the design, construction and operation of building and specially the demolition stage of projects. Selection of sustainable building materials represents an important strategy in the design of a building.[2]

II.l ENVIRONMENTAL PRODUCT DECLARATION – EPD

An Environmental Product Declaration - EPD is a registered document that communicates transparent and analogous information about the life cycle environmental performance of any manufactured products. It gives accurate, reliable and systematic environmental information for product. ISO 14025 is referred document for EPD, where it is referred as "type III environmental declarations".

This was available in 2002. During the 10 years span, differences and controversies in the declaration document lead to introduction of more rigorous rules for the building sector known as EN 15804. This document provides modular framework for EPD of product.

2.1 Modules according to EN 15804

EN 15804 introduced a modular approach, defining the different stages of the product life cycle. It starts at the product stage, including raw material supply, transport and manufacturing i.e. cradle to gate (module A1 to A3). This is followed by the construction process stage (module A4 and A5). The next is covering the use stage impacts (modules B1 to B7) i.e. use of products, maintenance, repair, replacement, refurbishment and operational energy and water use.

The end-of-life stage (modules C1 to C4) covers de-construction / demolition, transport to End-of-Life, waste processing and waste disposal processes. As an additional information module D covers benefits and loads beyond the system boundaries from reuse, recovery or recycling. (see Figure 1)

Information for evaluation of construction product														
Information on life cycle of construction product														Module D Benefits and loads beyond the system boundary
Product stage			Construction stage		Use stage					"End of Life" stage				
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	
Raw material supply	Transport	Manufacturing	Transport	Construction installation process	Use	Maintenance	Repair	Replacement	Refurbishment	De-construction demolition	Transport	Waste processing	Disposal	
					B6	Operational energy use								
					B7	Operational water use								
			Scenario			Scenario				Scenario				

Figure 1: The modular framework for environmental product declarations according to the EN 15804 standards

2.2 Environmental indicators according to EN 15804

The environmental indicators within EPD cover three groups

Group 1: Parameters describing environmental impacts

- Global warming potential (GWP) - kg CO2 equiv / m³
- Depletion potential of the stratospheric ozone layer (ODP) - kg CFC-11 equiv / m³
- Acidification potential of land and water (AP) - kg SO2 equiv / m³
- Eutrophication potential (EP) - kg PO4 equiv / m³
- Formation potential of tropospheric ozone photochemical oxidants (POCP) - kg Ethylene equiv
- Abiotic depletion potential for non fossil resources (ADP elements) - kg Sb equiv
- Abiotic depletion potential for fossil resources (ADP Fossil fuels) - MJ

Group 2: Parameters describing resource use – Primary energy

- Input of renewable primary energy (energy resource) excluding feedstock - MJ
- Input of renewable feedstock - MJ
- Total input of renewable primary energy (resource and feedstock) - MJ
- Input of non renewable primary energy (energy resource) excluding feedstock - MJ
- Input of non renewable feedstock - MJ
- Total input of non renewable primary energy (resource and feedstock) - MJ

Group 3: Parameters describing Secondary materials and Fuels and use of Water

- Input of secondary material - Kg
- Input of renewable secondary fuels - Kg
- Input of non renewable secondary fuels - Kg
- Input of net fresh water - Litre

Group 4: Parameters describing waste category

- Hazardous waste disposed
- Non hazardous waste disposed
- Radioactive waste disposed

Group 5: Parameters describing Output flows leaving the system

- Components for reuse
- Materials for recycling
- Materials for energy recovery
- Exported energy[3]

With reference to manufactures' and LCA practitioners' and verifiers experiences, the author Anna Nraune, et. al. (2013) states that, "*the new standard EN 15804 provides good guidance but lack in some important points. Eco-design activities require a reduction of the indicators to a manageable information base. In total the standard is rigorous, provide product transparency and support product improvements.*"

III. METHODOLOGY

Environmental Product Declaration is a tool that specifies performance of building material under various environmental parameters as described in section 2.2. This paper aims to investigate the usefulness of this tool for designers to select building material among the similar product range available in the market to reduce the environmental impact of building materials. In this paper, the environmental impact of Concrete masonry block, Autoclaved aerated concrete - AAC block, Pre-cast concrete block and generic brick is studied using EPD as a tool. For this purpose, current inventory data for manufacturing process of these materials as specified by manufacturers in the EPD is referred. The Environmental product declarations published by manufactures are taken as a reference for calculating and comparing the impact categories of these four masonry materials.

The impacts in each category of indicators are in different units of measurement. Hence, the level of impact in various categories cannot be compared as a whole. The impact of these materials under each category is compared separately. This paper also identifies the impediments in using this tool for the material selection at the end.

3.1 Limitation of data

The EPD of building material changes as per location of that material due to variation in input data. The input data is as per the availability of raw material, transportation to the manufacturing unit and manufacturing process for that building material. It also includes the fuel consumption in transportation and manufacturing unit. This research paper has limitation of the use of this data of masonry material from manufacture's referred data for calculation of environmental impact of Concrete masonry block, AAC block, Pre-cast concrete block and Generic brick.

Also, this research paper focuses on product stage of building material. Construction stage, Use stage and End-of-life stage is excluded from this study.

3.2 Information source of EPD data

The data referred for Concrete masonry block, AAC block, Pre-cast concrete block and Generic brick is EPD of manufactures from different companies. While doing so, the manufacturing process is taken into consideration. This helps in understanding of logic behind varying levels of impacts of different materials although the constituents of product being more or less the same. It also helps to understand the limitations these materials contain and gives compatible environmental data for construction products evaluated to the same standard. See Annexure for product details.

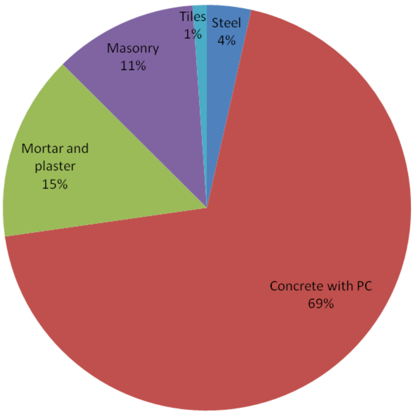
IV. BUILDING MATERIAL

In India, construction industry is not just the fastest growing industry but largest in terms of investment, volume of natural resources consumed, volume of materials and products manufactured, employment generated and environmental impacts, etc. Along with development, construction industry carries several challenges like emissions to air, land contamination, noise pollution, waste disposal and discharges to water[4].

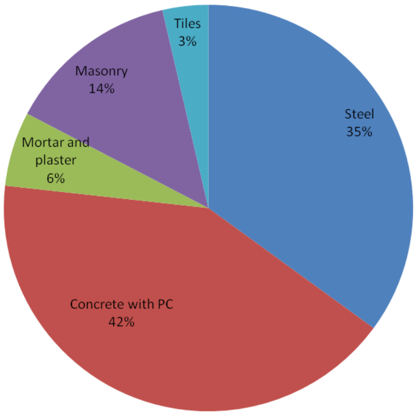
The construction and operation of the built environment has been estimated to account for

- 12-16% of fresh water consumption;
- 25% of wood harvested;
- 30-40% of energy consumption;
- 40% of virgin materials extracted;
- 20-30% of greenhouse emissions;
- 40% of the total waste stream of countries, 15-30% of which ends up in landfill sites;
- Up to 15% of purchased materials at jobsite ending up as waste.[5]

The above percentage shows, the amount of virgin materials extracted from natural resources are too large in quantity. This results in manufacturing of different building materials to same extent of extraction of raw material. Also the consumption of manufactured building materials is also high in quantity throughout the globe for infrastructure and building projects. The environmental impact of these building materials is at global level concern. In this scenario, Environmental architects and planners are conscious for selection of building material.



(a)



(b)

Figure 2 - (a) Building Material consumption and
(b) Embodied energy in Material consumed for project @ 20000 Sq. M.

After cementious products like concrete and mortar, masonry material is most consumed i.e. 11% among the total building materials in its construction. It is used in façade and internal partitions of residential building. Also the embodied energy consumption of masonry is as high as 14% of the total embodied energy of materials in same building.

4.1 Masonry material

Masonry materials are widely used in modern construction as they are the basic building materials for housing, public, and industrial construction.

Natural masonry materials are obtained by mechanical processing of rock (they may sometimes be produced without special processing), and artificial materials are produced by technological processing of a mineral raw material. The natural masonry materials have very less environmental impact as they are get merged in nature at the end of life. But artificial masonry materials are having significant environmental impacts due to its manufacturing process and ingredients used because they alter the composition, structure, and properties of the natural materials.

In modern construction, different masonry materials for external and internal walls are available in market. Concrete masonry block, Fly ash brick and block, AAC block, Pre-cast concrete block etc. are commonly used. These bocks are having significant environmental impact due to various ingredients used in its manufacturing process. It is important for environmental architects and planners to have a good understanding of the materials that they specify and this includes the initial environmental impacts that occur from extraction, processing and manufacture of masonry block material.

4.2 Environmental impact of masonry material

The environmental impact of different masonry materials vary as per the ingredients and the process adopted for manufacturing of that material. In this research study Concrete masonry block, AAC block, Pre-cast concrete block and Generic brick are studied for their environmental impact. The following table shows ingredients of these masonry materials in % per m³.

Table 1: The ingredients of masonry material

Sr. No.	Ingredients	Unit	Concrete masonry block	AAC block	Pre-cast concrete block	Generic Brick (1000 kg)	Generic brick Density 1550 kg/ m³
1	Cement	%	8	15-30	<10	--	--
2	Fine aggregate	%	53.8	--	--	12	12
3	Course aggregate	%	36.8	--	15-20	--	--

4	Water	%	1.4	--	<5	--	--
5	Additives and pigments	%	0.7	--	--	2	2
6	Quartzite	%	--	45-65	--	--	--
7	Gypsum	%	--	2-5	--	--	--
8	Quick lime	%	--	6-20	--	--	--
9	Aluminium powder	%	--	0.05-0.15	--	--	--
10	Recycled Ytong Slurry	%	--	10-20	--	--	--
11	Recycled Ytong powder	%	--	4-10	--	--	--
12	Recycled dust	%	--	--	70-76	--	--
13	Clay	%	--	--	--	86	86

The ingredients of different masonry materials vary as per the product manufacturing process. The product in its technical life affects environment under different categories as defined in EPD.

Table 2: Comparison of parameters describing Environmental Impacts of Concrete masonry block, AAC block, Pre-cast concrete block and Generic brick

Sr No	Category Indicator	Unit	Concrete masonry block	AAC block	Pre-cast concrete block	Generic Brick (1000 kg)	Generic brick Density 1550 kg/ m³
1	Global Warming Potential	kg CO2 equiv / m³	362.00	167.10	9.88 E+01	158.00	244.90
2	Acidification Potential	kg SO2 equiv / m³	2.00	26.53 E-01	2.71 E-01	1.35	2.09
3	Eutrophication Potential	kg PO4 equiv / m³	0.80	58.38 E-02	6.87 E-02	0.05	0.0775
4	Poisons and Ozone Depletion Potential	kg CFC-11 equiv / m³	8.60 E-06	8.064 E-07	4.04 E-06	8.69 E-05	13.47 E-05

5	Photochemical Ozone Creation in tropospheric ozone - POCP	kg Ethylene equiv	0.60	77.676 E-03	1.73 E-02	0.0751	0.116
6	Depletion of Abiotic Resources - Elements	kg Sb equiv	Not available	46.98 E-05	2.93 E-05	4.34 E-07	6.727 E-07
7	Depletion of Abiotic Resources - Fossil	MJ	Not available	78.15 E+02	6.55 E+02	2840.00	4402.00

Table 3: Comparison of parameters describing Resource and Energy consumption of Concrete masonry block, AAC block, Pre-cast concrete block and Generic brick

Sr No	**Category Indicator**	**Unit**	**Concrete masonry block**	**AAC block**	**Pre-cast concrete block**	**Generic Brick (1000 kg)**	**Generic brick (1550 kg per m³)**
			Total primary energy consumption				
1	Non renewable fossil	MJ	1815	1325.50	6.77 E+02	2810	4355.50
2	Non renewable nuclear	MJ	117				
3	Renewable (solar, wind, hydroelectric, and geothermal)	MJ	20	12.10	2.05 E+01	58.30	90.365
4	Renewable (biomass)	MJ	79				
			Total material resource consumption				
1	Non renewable material resources	Kg	2082	Not available	1.50 E+03	21.4	33.17
2	Renewable material resources	Kg					
3	Net fresh water	Litre	32.60	20.722 E-02	1210	759	1176.45
			Waste generation				
1	Non hazardous	Kg	4.25 E-02	4.88 E-01	3.81 E-02	1.38	2.139

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	waste generated						
2	Hazardous waste generated	kg	0	1.21 E-01	0	1.60	2.48

V. DISCUSSION

5.1 Global warming potential

The global warming potential is associated with carbon dioxide emission and resulting from burning fossil fuels in extraction, manufacturing, transporting, installing, maintaining and disposing of construction material. Combustion of fossil fuel in product stage emits carbon dioxide and Green House Gases - GHG. These gases accumulate in the atmosphere and trap solar heat which in turn increases the earth's average temperature.

The global warming potential is measured in units of CO2 and its equivalent for other GHG i.e. methane (CH4), nitrous oxide (N2O), hydroflurocarbons (HFCs), perflurocarbon (PFCs), sulphur hexafluoride (SF6).

Clay brick manufacturing process requires fossil fuel consumption and thus contributes to Green House Gas emissions. These emissions include particulate matter (PM), sulfur dioxide (SO2), sulfur trioxide (SO3), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO2), metals, total organic compounds (TOC) (including methane, ethane, volatile organic compounds [VOC], and some hazardous air pollutants [HAP]), hydrochloric acid (HCl), and fluoride compounds.[6]

Electricity is the primary energy source for AAC block and Pre-cast concrete block due to heavy machinery use in manufacturing process. The emissions due to coal burning at thermal power plant for electricity generation become part of emission of these two masonry materials.

There are two factors that lead to the negative environmental impacts during the extraction of raw materials i.e. aggregates including removal of vegetation and contamination of ground water. In addition, emissions of Particulate Matter - PM and unpredictable materials are caused during crushing, grinding and mixing of raw materials. The manufacturing process of concrete involves separation of different sizes of aggregates and feeding of different sizes of aggregates and different grades of concrete into cement silos. The material handling process at these stages adds particle emissions in the air and also involves fuel consumption in transportation at different sources leading the contamination of air through emission. Thus, Global Warming Potential of concrete blocks (AAC, Pre-cast) is higher than burnt bricks.

5.2 Acidification potential

Combustion of fossil fuel also emits sulphur dioxide, nitrogen oxide, hydrofluoric acid, ammonia, and other acidic air pollutants that react with water in atmosphere and increase acidity of rain water, which in turn acidifies lakes and soil and damage ecosystem. Acidification potential is measured in units of SO2 and equivalent release of SO2 by other gases.

The fuel consumption for operating heavy machinery units for manufacturing of concrete masonry blocks and for transportation of raw materials in the factory contributes to its Acidification Potential. The cement content in concrete mix of AAC block is higher as compared to in-site concrete blocks and Pre-cast concrete blocks. Since the acidification potential of cement itself is very high, it contributes to higher acidification potential of AAC blocks.

The manufacturing process of Pre-cast is concrete blocks involves consumption of electricity that includes emissions from thermal power plant. However, the Acidification Potential of Pre-cast concrete blocks is lowest among all and masonry materials due to comparatively lower cement content and controlled manufacturing conditions.

5.3 Eutrophication potential

The increased concentration of Nitrates and phosphates can adversely affect the living organism on Earth. Burning of fossil fuel in manufacturing process of construction material adds atmospheric nitrogen pollution which results in contribution to eutrophication.

Eutrophication potential of fresh water is degraded when Nitrogen and phosphorous from wastewater causes excess growth of algae, which then depletes oxygen level in water resulting in the suffocation of aquatic life. Eutrophication potential is measured using the reference unit of nitrogen and phosphate equivalents.

Although, the proportion of concrete mix for these varieties of concrete mixes varies the manufacturing process of these blocks is similar till the pouring of concrete in moulds. However, the curing process varies greatly among these materials. AAC blocks are steam cured while Pre-cast concrete blocks are cured through heating process and concrete masonry block are cured with fresh water. The curing by fresh water in in-site concrete blocks leads to mixing of cement particles with water that leads to contamination of waste water and degrades quality of waste water.

The water consumption in brick manufacturing is lesser as compared to other concrete block. Also mixing of soil in waster during manufacturing process does not deplete the ground with quality.

5.4 Poison and ozone depletion potential

The thinning of the atmosphere's ozone layer allows increased ultraviolet radiation to reach the earth. This in turn results sun related problems to living organisms on Earth. The major ozone depleting gases are CFCs, HCFCs and halons and radial molecules released by these gases damage ozone (O3) layer.

Ozone depletion potential of any product is expressed as the loss of ozone due to increase of the reference substance CFC-11. Due to this, ODP is measured with reference unit of kg chlorofluorocarbon-11 (CFC- 11) equivalent.

Poison and ozone depletion potential of brick is lowest among all four masonry materials. This is due to the less emission of chloro-fluoro-carbons (CFCs), hydro-chloro-fluoro-carbons (HCFCs), halons, and methyl bromide (CH3Br) in manufacturing process of brick masonry material.

In AAC block, the aluminum is used as a foaming agent. The pours usually have a diameter 0.5 - 1.5 mm and are filled exclusively with air. The used substance creates calcium hydrosilicates which correspond to the naturally occurring mineral tobermorite. The reaction of the material is complete when removed from the autoclaved. This reaction result in few gases emissions which result in thinning of the atmosphere's ozone layer. Due to this Poison and Ozone Depletion Potential of AAC block is highest among all four masonry materials.

5.5 Photochemical ozone creation potential

Photochemical Ozone Creation or Smog Creation Potential (POCP) is caused by the emission of nitrogen oxides (NOx) due to fuel combustion and VOCs emission from solvents which results in decreased visibility, eye irritation, respiratory tract and lung irritation, and vegetation damage. The effects of photochemical ozone variation depend on the geography, climate and other characteristics of location where the construction material is manufactured. POCP is expressed using reference unit, kg ethane equivalent.

POCP is maximum in the manufacturing of Concrete masonry block due to handling of raw materials such as various sizes of aggregate and grades of cement on plant site and also emissions during diesel combustion in transportation of material on plant site. Also, fuel consumption in heavy machinery used in manufacturing process of Concrete masonry block release emissions in air.

POCP is also high in brick manufacturing due to burning of fossil fuel in drying and firing process of brick manufacturing. This results in decreased visibility, eye irritation, respiratory tract and lung irritation for the workers working in plant.

POCP is lower in Pre-cast concrete block and AAC block since these masonry materials are manufactured in highly controlled factory condition and supervision by experts. Also the emissions of pollutants are controlled by water spray during the process.

5.6 Abiotic Depletion Potential (Fossil fuels)

Abiotic Depletion Potential (Fossil fuel) - ADPF shows the same trends as the other categories driven by the use of fossil fuels, natural gas and grid electricity, diesel combustion in plant machinery, together with fossil fuel derived raw materials are the major contributors to depletion of fossil fuel resources or feedstock in nature. These resources available in nature which consumed in the product stage are measured in MJ.

This is higher in AAC block due to heavy plant machinery use in entire process of manufacturing and steam generation for curing process of block. Steam generation in a large space consume excessive energy and fuel for curing process. Also it is a continuous process to keep the steam at same flow rate throughout the curing process.

Abiotic Depletion Potential (Fossil fuels) in AAC block is followed by Brick manufacturing due to combustion of fossil fuels in drying and firing in manufacturing process.

While, it is lower in Pre-cast concrete block which is cured by heating. The temperature of moist heating area needs to be controlled throughout the curing process.

5.7 The Abiotic Depletion Potential (Elements)

Abiotic Depletion Potential (Elements) - ADPE impact category is related to extraction of virgin Abiotic material from the natural resources, e.g. extraction of aggregates, metal ores, minerals, earth etc. The largest source of ADPE impacts is grid electricity use at plant and the use of electricity in the natural gas production processes.

The Abiotic Depletion Potential is measured on basis of extraction of elements from reserves, remaining reserves and rate of extraction within Earth’s crust and compared to the reference case, Antimony (Sb). Thus abiotic depletion is measured in kg Sb equivalent.

This is found higher in Brick manufacturing due to mining of Abiotic material i.e. soil which is major ingredient in Brick product. Also the fossil fuels burnt in drying and firing process consume local fuel materials available in nearby area of plant site. While AAC block and Pre-cast concrete block consume less virgin material like aggregate, minerals, etc. Also the manufacturing process of these two cementious materials is under controlled environment, so consumption and loss material is less as compared to open plant of Brick manufacturing.

5.8 Primary energy demand

The embodied energy of the materials is the energy that would be released if the product is burned. While, the primary energy consumption of material depends on the source of energy utilized during manufacturing process of product. This energy may be derived from renewable or non-renewable source and measured in MJ.

Cement is energy intensive product. The concrete product such as Concrete masonry block, AAC block, Pre-cast concrete block consume cement as their one of the important ingredients. Therefore its energy demand reflects in its Primary Energy Demand calculations. Since there is no burning process in the manufacturing of Concrete block, AAC block and Pre-cast concrete block, it results in the lower energy consumption than the clay brick manufacturing.

The technology adopted for brick manufacturing process consumes extensive use of fossil fuels in its drying and firing process, which reflects in its higher Primary Energy Demand. The heat generated by the fossil fuels are then released in atmosphere and not utilised for successive manufacturing cycles of brick product. It requires same fossil fuel consumption for the next cycle. Thus Primary Energy Demand of brick manufacturing is higher among all four masonry materials.

7.9 Material resource consumption

There is only a finite amount of each mineral available in Earth’s crust. Mineral deposits can't be return to the earth as ore once it is mined, no matter how much it is reused or recycled.

5.9.1 Material consumption

All masonry blocks require non-renewable materials as their constituents. However, all three types of cementious masonry materials discussed here consume more amount and varieties of ingredients as compare to fired clay brick (sand and clay).

The various ingredients (cement, sand, aggregate, additives and pigments, etc.) of cementious masonry materials consume natural resources in their production. This reflects in calculation of the natural material resource consumption of these masonry products.

The EPD data shows that, maximum natural material resource consumption is with concrete masonry block followed by Pre-cast concrete block. While it is minimum with fired clay brick due to minimum ingredients in manufacturing of product.

5.9.2 Fresh water consumption

Source of fresh water during the process is either through the use of mains (potable) water or, through pumping boreholes i.e. ground water on plant site. Also its use in product stage of building material affects the quantity of fresh water consumption. The average fresh water consumption is quantified in m^3.

In cementious block manufacturing, there are two ways of accelerating the eventual strength and the rate of strength gain to the final product resulting from curing process – either adding more cement to the mix or curing in moist warm curing chambers. In AAC block, steam curing for secondary curing process consumes less fresh water. Also same steam is utilised for number of cycles in AAC block manufacturing.

In Concrete masonry block, the secondary curing consumes lot of fresh water. This curing process also affects energy consumption for pumping and disposal of water. But the waste water containing cement particles can be utilized in successive masonry block manufacturing.

In brick, the curing process is not required, but the raw material preparation consumes lot of Fresh water in manufacturing. The mining, batching process requires sprinkling of water during the process to reduce emission of soil particles in air. Mixing and blending consume water quantity in manufacturing process. Drying and firing process evaporate the water molecules. The water consumed in entire process cannot be reused or recycled resulting in higher water consumption in brick manufacturing.

The EPD of four masonry materials is showing maximum consumption of Fresh water in Pre-cast concrete block. In compressing phase of raw material mix, the waste water generated is driven off from the area and this water is not utilised in successive process. Thus it results into more fresh water consumption of Pre-cast block manufacturing process as compared to other masonry materials.

5.10 Waste generation Potential

Waste generation potential in AAC and Pre-cast block is less due to controlled condition manufacturing process. Whatever waste generated either through the transportation and storage of raw materials to plant site, handling of materials during manufacturing process are recycled through recycling systems in plant.

The raw materials like recycled slurry and dust used in manufacturing of AAC block and Pre-cast concrete block respectively, the waste material from landfill site gets utilized in product which also reduce consumption of virgin material in product and the management of these waste will be slightly reduced. AAC block generate hazardous waste due to chemical content in product. Only additives and pigments cannot be recycled.

Burnt / fired Brick generates waste at manufacturing plant due to handling and storing of material. And the entire manufacturing process of brick is not controlled to extent the manufacturing of AAC block and Pre-cast concrete block are controlled.

To summarize, Pre-cast concrete block is having less Global Warming Potential, Acidification Potential, Eutrophication Potential, Poison and Ozone Depletion Potential, Photochemical Ozone Creation or Smog Creation Potential, Depletion of Abiotic resource (Fossil and Element), Primary Energy Demand, Material Resource Consumption and Waste generation Potential. Only its Fresh water demand is high among all four masonry materials. This is followed by generic brick which is having lower environmental impact as compared to Concrete masonry block and AAC block. It’s Depletion of Abiotic Resources (Element), Primary energy demand and waste generation potential is higher as compared to Concrete masonry block and AAC block. The use of these materials will reduce the environmental impact due to material consumption in construction industry.

The Global Warming Potential, Eutrophication Potential, Photochemical Ozone Creation or Smog Creation Potential and Material resource consumption is higher in Concrete masonry block. In case of AAC block, Acidification Potential, Poison and Ozone Depletion Potential and Depletion of Abiotic Resource (Fossil) is higher among all four materials. This is due to the use of cement in manufacturing.

This research paper shows that, the environmental impacts of extraction, processing and manufacturing of raw materials used in manufacturing of masonry material directly influence the environmental impact of that masonry product. Therefore selection of raw material is one of the important decision along with manufacturing process adopt for masonry material production.

Utilisation of fly ash in the cementious masonry product manufacturing activity will contribute to savings in natural resources, mainly the land (top soil), water, coal and limestone which are contributed due to use of cement material in these products. Also, water will be saved due to reduced fly ash disposal from thermal power plants.

VI. CONCLUSIONS

It is important for Architects and building sector stakeholders to understand the ingredients and manufacturing process of masonry material while selecting product for their building. This help to reduce long term environmental impacts due to built environment of building industry.

EPD as a tool can give general guidelines for material selection to the designers. However, it has certain limitations. Firstly, the data under different categories is in different units of measurement. Therefore, overall environmental impact of a particular material cannot be assessed. The impact of these materials under each category can be compared separately. Secondly, it is difficult to gauge what parameters are more significant than the others among all the parameters as a basis for material selection. Despite of these lacunae, EPD can be seen as a self assessment tool for the manufacturers for their product development and improvement.

1. Annexure: EPD data source of masonry materials

Sr. no	Product name	Company name	Address	Date of issue	Date of expiry
1	Midwest block and brick	NSF Sustainability, Sustainability assured	NSF international 789 N.Dixboro Rd. Ann Arbor MI 48105 USA	May 7, 2015	Five years
2	Ytong, Autoclaved Aerated block	TURK YTONG SANAYI A. S.	Turk Ytong Sanayi A. S. Central production site – Pendik factory Pendik 34899 Istambul / turkey	April 22, 2015	April 21, 2020
3	Enviroblock dense brick (Precast concrete block)	Aggregate Industries UK Ltd.	Aggregate Industries UK Ltd. Bardon hall Copt Oak Rd Markfield	February 26, 2015	February 26, 2020

4	BDA generic brick	Brick development Association	Leicestershire LE67 9PJ The Building centre 26 Store street London WC1E 7BT	August 1, 2014	December 11, 2018

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