BUILDINGS AS PLASTIC WASTE SINKS PLASTIC WASTE AS AN INFILL MATERIAL IN CAVITY WALLS – AS A THERMAL INSULATION LAYER

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Abstract

Rapid urbanization due to quick transitions and inventions in technologies and products leads us to develop and cater to the needs of the present generation, but with a question of sustainability. Plastic is one of those inventions which was a good solution at its initial production. Then slowly, it made us realize its disposing disability. It is deteriorating. This research, covers a few efficient iterations of its upcycle as infill materials in built spaces that reduce thermal transmission and improve the overall building energy consumption, improving the climatic response of the built area and terminating the contamination and misuse of land and other resources.

Keywords : Plastic Wastes, Infill Material, Thermal Insulation, U-Value

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1.1. Introduction

Modern-day plastic production and usage have hiked. Mainly, the problem arises when it is not reused and recycled efficiently. People dispose of it randomly in public spaces, contaminating other resources. Conventional disposal methods like landfilling eat more space, and decomposing takes centuries until when the land won't be usable in this case. This land is potentially a waste. It will not be feasible for the future, as the land requirements for various land use functions will increase when the population multiplies.

Thus, volumes and spaces in buildings, wherever there is a cavity or in need of thermal and hydro insulation, can use the property of plastics and satisfy the function. The plastic waste processed into a specific form and its use as the infill will reduce the contamination, pollution, and land wastage over time and make this problem of plastic pollution non-existent.

1.2. Overview

As a solution to the issue of plastic pollution, this research investigates the possibility of plastic waste being used as insulation material, infilled in cavity walls. Literature Study of the source and scope of the plastic waste generated led to the choice of the material used for the sample. Further, the requirements of a good insulation material's physical quantities are studied, with some materials' thermal resistance values, to gain an idea of the range of good thermal resistancesAfter studying various sources of plastics and their scope to be upcycled as an insulation material, materials required for the sample were gathered. Further, with sets of procedures, the model was safely crafted.

The research results, i.e., thermal insulation of the material, are calculated post conducting an experiment and kept for the future scope.

1.3. Aim

To make an infill insulation material upscaling plastic waste.

1.4. Research Significance

i) This research determines the scope of plastic waste being upcycled as an insulation material infilled in a cavity wall.

ii) Investigates the possibility of this infill insulation material replacing the conventional insulation material.

iii) Applying this material in the cavity walls will reduce energy consumption inside the built spaces for cooling/heating. Thus, buildings can be designed as energy efficient.

1.5. Objectives

i) To Identify the Types of plastics, their waste sources, and management.

ii) To determine the type of plastic waste for upcycling and making a sample, i.e., the Infill material.

iii) To experimentally find the thermal resistance of the produced model.

1.6 Methodology

i) 2. Study of Physical Quantities affecting thermal performance of an infill wall

i) 2.1. Thermal conductivity

ii) 2.2. Thermal Transmittance (U-Value)

iii) 2.3. Thermal Resistance

iv) 2.4. Thermal Insulance (R-Value)

v) 2.5. Cumulative R – Value

ii) 3. Study of Various Infill materials and their U-Values

iii) 4. Types of plastics, its waste sources and management

i) 4.1. Types of plastics

ii) 4.2. Plastics – Contemporary waste management – Nagpur (The need for it to be Upcycled)

iii) 4.3. Conditions of Biodegradable, Oxo-biodegradable, Compostable plastic bags

iv) 5. Infill Material

i) 5.1. Infill material Iterations

ii) 5.2. Material Choice

i) Justification

iii) 5.3. Making the sample

v) 6. Experimental Test

i) Results

i) The Theoretical U - Value of the material

ii) The Experimental U - Value of the material

1.7. Scope for the future

1. Identifying the R-Value of the infill material experimentally through “heat transfer through composite wall” apparatus

2. To identify the procedure to make or mass produce it, size availability and installation method to plot the embodied energy. (right after waste segregation)

3. Running climatic simulations for a basic built space, with the obtained R-Value.

1.8. Scope of the Study

The scope of the study will be focusing on

i) To Upcycle the plastic waste into Insulation material infilled in Brick cavity walls.

ii) To choose the material and propose a way to Upcycle it, to make a sample.

iii) To determine the thermal resistance of the sample.

1.9. Limitations of the Study

The study does not focus on

iv) Applicability of the infill material to cavity walls of other materials.

v) Factors such as damp prevention, sound insulation, fire resistance, efflorescence, etc.

vi) *Life-span, durability, and maintenance of the infill material.*

2. Study of Physical Quantities affecting thermal performance of an infill wall

2.1. Thermal conductivity – The rate of heat transfer per unit area of a **1m** thick material under stable conditions, with 1°C (or k) temperature difference between two faces. **Denoted by k**. Watt per meter x k, [W/m·K].

2.2. Thermal Transmittance (U-Value) – Heat transfer per unit area w.r.t the thickness of the material per unit temperature difference between two surfaces of the material. Reciprocal of thermal resistance. [$W/m^2 \cdot K$]. (ToolBox, 2003) (greenspec, n.d.)

U = 1/Rt

Rt = Thermal Resistance.

2.3. Thermal Resistance – The temperature difference between two surfaces of the insulation layer when a unit heat energy passes through it.

Different components with different absolute thermal resistance (Rt) will add up to give the total R-Value. Rλ (material constant), in kelvin metres per watt (K·m/W) is a constant value of resistivity of particular material. (ToolBox, 2003) (greenspec, n.d.)

Rt = L/kA *(U=kA/L, where we get the transmittance after dividing constant conductivity by thickness of material)*

L = Thickness of material (in meters)

K = Thermal Conductivity of material (a constant) A = Area of the plane (m^2)

2.4. Thermal Insulance (R-Value) – Thermal resistance of a material per unit area, in $m^2 \cdot K/W$). Inverse of (U-Value).

Thus, find the U-Value of the wall with the prepared plastic infill material, experimentally

U-Value = 1/(Sum of all R-values)

2.5. R-value

Each Layer of wall (Brick + Cavity + Plastic Infill + Brick) will have individual R-Values.

Rate of heat Supplied (W = I/A)

Heat flux (heat per unit area) q = W/A

Thermal Resistance per unit area (**R-Value**) is (Temperature difference between surfaces) / Heat flux) = **$(T_1-T_2)/q$**

To find the ultimate R-Value, the temperature difference between all layers can be found and then applied to find. (ToolBox, 2003), (greenspec, n.d.)

3. Study of Various Infill materials and their U-Values

The U-Values mainly depends upon K (The Thermal conductivity), the thickness and area of the insulating layer.

Higher the U- Values, lower the R- Values and thus lower the thermal resistivity.

INSULATING MATERIAL	CONDUCTIVITY k (W/m.k)	U – VALUE AT 1000MM (K/1)
Vacuum	0	0
Air (atmosphere)	0.0262	0.0262
Wood fibre	0.038	0.038
Cellulose (sprayed)	0.038 – 0.040	0.038 – 0.040
Rock mineral wool	0.045	0.045
Sheep wool	0.039	0.039
Styrofoam	0.033	0.033
Urethane foam	0.021	0.021
Aerogel	0.014	0.014
Extruded Polystyrene (XPS)	0.033 – 0.035	0.033 – 0.035
Polyurethane foam	0.023 – 0.026	0.023 – 0.026
Phenolic foam	0.020	0.020
Glass mineral wool	0.035	0.035
Straw	0.08	0.08
Cellular glass	0.041	0.041
Hemp	0.039 - 0.040	0.039 - 0.040
Polyethylene (low density)	0.33	0.33
Polyethylene (high density)	0.42 - 51	0.42 - 51

(greenspec, n.d.), (ToolBox, 2003)

4. Types of plastics, its waste sources and management

4.1 Types of plastics

Plastics can be characterized by thermosets and thermoplastics based on their composition or physical and chemical properties. Thermoplastics are recyclable. By heating, it can be melted and molded, and hardened by cooling. This cycle of melting to hardening to melting makes it mechanically recyclable. Thermoplastics can be characterized based on their structural organization (chemical bonds and level of their properties and functioning).

4.1.1 Thermoplastics Polyethylene terephthalate (PET)

These thermoplastics have fossil feedstocks as sources. **They are used in bottle packaging and textile industries contemporarily**. A 2016 study reported that "Ideonella sakaiensis bacterium" decomposes PET and uses the decomposed products as a carbon source for its growth. This biodegradation of PET by the enzyme into subunits (catabolic reaction) can be an asset in this process of PET recycling decomposition, through which waste management can be enhanced. (Evode, 2021)

High-density polyethylene (HDPE)

Also known as alkaline or polyethylene. It is a low-cost, linearly structured thermoplastic with low branching. Produced under low temperature (70-300◦C) and low pressure (10-80 bar). "**Typical uses of HDPE include soap containers and cleaning solutions, freezer bags, shopping bags, faux wood planks, food and drink storage, pipes, protective helmets,**

bottle caps, vehicle fuel tanks, recycled wood-plastic composites, and insulation." (Evode, 2021)

Polyvinyl chloride (PVC)

"The largest usage of chlorine gas is the formation of PVC worldwide. Overall, 16 million tons (40% per year) of chlorine production is used in daily human activities. PVC has the largest production volume of organochlorine, which could be defined as a large class of chemicals that have come under scientific and regulatory scrutiny in the past years due to their global distribution and the serious impacts on the community. Most plastic wastes that do not contain chlorine in their composition have more adverse effects on the community than the plastic waste resulting from plastics. Environmentally adverse effects result from vinyl production, the formation of toxic chemicals, and overconsumption of energy and resources in different stages of production." (Evode, 2021)

"Ethylene is natural gas or petroleum and chlorine gas that can be mainly synthesized from sea salt by high-energy electrolysis. These are the two basic subunits of vinyl production. Ethylene dichloride (EDC), scientifically named as 1,2-dichloroethane is synthesized from chlorine gas and organic chemical ethylene by chemical processes where chlorine and ethylene are combined. This production process is also known as chlorination. In this process, organic HCl is produced as a byproduct, and this byproduct is combined with excess ethylene to produce more EDC through the chemical production process known as oxychlorination. Simultaneously, the EDC produced is further converted into chloroethylene (VCM–vinyl chloride monomer) through the chemical transformation reaction known as pyrolysis. The monomers of VCM produced through the pyrolysis process are joined together to make a long chain of PVC commercially named white powder. Pure PVC is combined with several other chemicals, including colorants, plasticizers, stabilizers, and other necessary additives that can add any specific property of the desired plastic functioning. The pure form of PVC is not particularly useful due to its brittleness, rigidity, and it can gradually catalyze its decomposition with intensity from ultraviolet light. Different additives are added to the polymer to increase its moldability and flexibility to produce useful PVC. **PVC is commonly used in cleaning solution containers, water, and sewage pipes, clothing, water bottles, medical containers, Signage, furniture, tubing, flooring, electric conductors, and other useful cables, cladding, vinyl records.**" (Evode, 2021)

Low-density polyethylene (LDPE)

"Defined as a translucent and semi-rigid long chain of identical subunits compared to HDPE, which are highly branched with long-chain and short-chain monomers. LDPE is made under specific conditions of high temperature (80–300 ◦C) and pressure through free radical polymerization. The LDPE is synthesized by 4000 to 40,000 carbon atoms having several short-branches and sub-branches. LDPE can be made through two different techniques, such as tubular routes and stirred autoclaving. Currently, tubular reactors are more used than autoclaving due to their advantages of higher ethylene transformation rate. **LDPE is commonly used in containers, drink cartons, bin-garbage, work surfaces, ring drink holders, laundry bags, machine parts, lids, playground fixtures, protective shells, computer hardwires, trays, bin-bags, and laundry bags.**" (Evode, 2021)

"**Polypropylene (PP)** is the thermoplastic polymer used in different applications. Its empirical formula is $(C3H6)n$. A continuous chain makes it of polymerization reaction of propylene to the polymer named polypropylene classified in the group of polyolefins, a half non-polar organic molecule and partially crystalline. PP was invented in 1954 due to its advantages as polyolefins, which has less density than other commodities. It has several other benefits, e.g., chemical resistance, which allows PP to be processed through several conversion routes, like extrusion and injection molding. Its physical and chemical properties are related to high- temperature resistance and chemical branching. **PP is able and has a high priority to fabricate different household items, including pails, instrument jars (it can be frequently cleaned for clinical environment use), funnels, trays, and bottles. Polypropylene is a colorless material that exhibits excellent mechanical properties, making it favorable to use than polyethylene. Polypropylene is commonly used in packaging tape, lunch boxes, crisp bags, straws, food containers, bottle caps, clothing, hobbyist model, supplies, and surgery tools and supplies**.” (Evode, 2021)

4.1.2 Thermoset plastics

“Thermosetting or thermoset plastics are synthetic materials that pass through a series of physicochemical transformation processes under different heat treatments, assisting the creating of a three-dimensional linkage. This transformation is not a reversible process. After heating treatment, these thermosets molecules cannot be reformed or re-molten. Thermosets physical state can be changed from liquid with a low degree of viscosity to solid with a high melting point; this shows that different materials with some specific chemical and physical characteristics can be formed from thermosets. In general, thermosetting subunits or monomers have low viscosity, which allows them to be modified and make them easy for the consumer; different additives are used on thermosets to maximize and optimize the performance of thermosets and will enable them to be applied in different specific uses like others.” (Evode, 2021)

“Polyurethanes refer to a polymer made by polymerizing organic monomers known as urethane, commercially named a carbamate. Many polyurethanes are thermoset are also called thermoplastic polyurethanes. Physical and chemical properties of polyurethane, like its versatility allow these polymers to be widely used in different applications such as coatings, foams, adhesives, paints, upholstery, and insulators. Like other polymers, polyurethanes also depend on petrochemicals as a basic material or subunits in their main constituents.” (Evode, 2021)

4.2. Plastics – Contemporary waste management – Nagpur (The need for it to be Upcycled)

Overall Plastic waste generated in the district is 26.9MTD. Nagpur being largest city generates maximum waste with 16MTD. Door to door collection and segregation of plastic is implemented 100% almost in all ULBs. There are total 24 Plastic Waste Collection Centre across the district with 263 Plastic Waste Pickers and 247 numbers of Plastic Waste Recycler and 10 Plastic manufacture. 1MT/Month plastic is use in road making and 244.8MT/Month is sent to for Co-processing in Cement Kiln. PW Management Rules, 2016 is implemented in all the ULBs. However, no information is available related to programme conducted for mass awareness of public regarding plastic waste. (Environment Department, 2021)

Therefore, directly from the waste collection centres, segregate HDPE bags and send it to manufacture the infill material.

4.3. Conditions of Biodegradable, Oxo-biodegradable, Compostable plastic bags

“There is clear evidence that discarded single-use carrier bags are accumulating in the environment. As a result, various plastic formulations have been developed which state they deteriorate faster and/or have fewer impacts on the environment because their persistence is shorter. This study examined biodegradable, oxo-biodegradable, compostable, and high- density polyethylene (i.e., a conventional plastic carrier bag) materials over a 3 year period. As a qualitative assessment of functionality, the bags were loaded with typical groceries from a local supermarket (weight 2.25 kg). Oxobio1, Oxobio2, biodegradable, and conventional were still functional and retained the items with no breakages. However, the compostable bag type (which was only present in the soil environment for 27 months) was unable to hold any weight without tearing." (Napper & Thompson, 2019)

5. Infill Material

5.1. Infill material Iterations – identifying the best composure

vii) Melting Plastic waste by containing it in a metal container through hot oil, such that there will be no fumes or smoke. Pollution free plastic melting. Then cast it into a new form, to mass produce.

viii) Normal compressing of plastic waste

ix) Plastic compressed between Foam Boards, MDF or XPS

x) Plastic Compressed and bonded using bonding agents.

xi) Plastic Sheets extracted out of HDPE bags, fused together to the desired thickness by temperature increase. Using two of these fused layers, with cavity in between created by bottle caps.

5.2. Material Choice

Garbage bags (made from LDPE and HDPE), Bottle caps

5.2.1. Justification

Garbage/ Trash bags are widely used to dispose waste into the landfill site. Thus, currently, they are highly unlikely to be recycled. Procuring these bags, depending upon the biodegradability of these bags, and upcycling it to an insulation material will terminate many negative effects of these bags being landfilled. Moreover, Trash bags labelled as Biodegradable, Oxo-biodegradable, Compostable are still not fully friendly to the environment.

Thus, the choice for the sample material is Oxobio and LDPE.

5.3. Making the sample

5.3.1. Procedure

Bind the LDPE sheets together to a required thickness by stacking them on top of other and pressing with warmer temperature. Bind sheets to the deserved thickness, this is now a unit. (A).

Make another unit of sheet to the deserved thickness (B). The fused sheet is now an unit, Use two of these fused units to make one panel of the material. Attach both the sheets with the bottle caps in between both, which creates cavity and thus increases the Thermal Resistance.

Figure 1. Unwrapped LDPE sheets placed in cross-laminated pattern

5.3.2. Detailed Procedure

Firstly, Cut sheets from Plastic Bags and lay the Plastic sheets on top of the heat resistance surface. Then, lay the plastic sheets on top of each other and terminate with another parchment paper on top of the stack and Switch on the iron with medium temperature settings, Press the iron starting from the center of the Plastic sheet and then slowly go on to the edges, firmly pressing. Iron the whole sheet.

After Ironing the whole sheet a several times, lift up the parchment paper to check if the sheets are fused together. If sheets aren't fused then increase the temperature and if there are holes on the sheets then, reduce the temperature. We get semi fused HDPE sheets through this process, with cavities in between. To get thicker sheets, remelt the sheet by keeping it on an oven. Metal baking sheet on both sides of the sheet and then heat resisting weights are must. (optional)

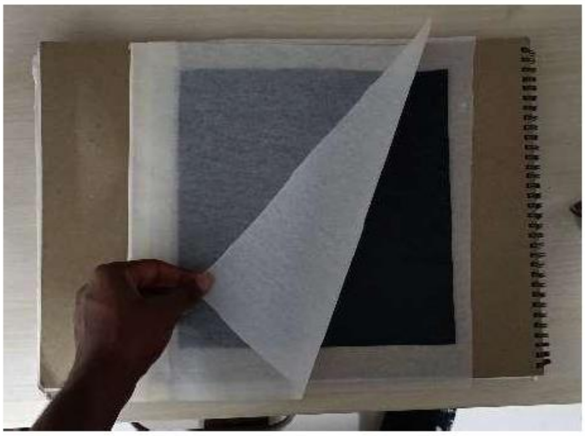

Figure 2. Folded LDPE sheets Placed between Parchment Paper

Figure 3. Fusing LDPE sheets by firmly pressing from the middle to the edges

Since the air cavity percentage will be more without binding them to the fullest, we proceed without getting it fused with the oven.

Now, upon one unit of these fused sheets, bind bottle caps with desired center to center distance, making a grid, thus making the sheets rigid. Bind another unit of these fused sheets on the other side of the cap, such that the bottle caps are in the middle, giving rigidity and also a cavity which increased the thermal resistance.

Figure 4. Fused LDPE sheets

Figure 5. Bottle caps creating a cavity between the two layers

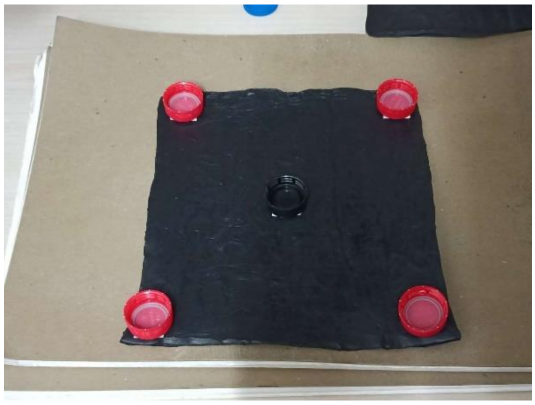

Figure 6. Bottle caps equidistantly placed on Fused LDPE sheets

Figure 7. Bottle caps on fused LDPE sheets

Figure 8. Section of the Sample

Experimental Test (Scope of future)

5.4. Aim: Identifying the R-Value (overall thermal resistance) of the infill material experimentally through "heat transfer through composite wall" apparatus.

5.5. Materials Required:

Infill Material (according to the sample requirements), Heat Transfer Through composite wall apparatus

5.6. Procedure:

1. Arrange the infill material in the apparatus accordingly.
2. Switch on the apparatus with dimmer stat value set at zero, using the dimmer stat change the input power of heat. Keep the knob at a specific value.
3. Take down the readings of voltmeter, ammeter and the temperatures from all the thermocouples in the intervals of 10 minutes.
4. Wait for the temperature readings to become stable (~20 minutes)
5. Use the values of the temperature for the calculation.

Table 1. Observations from the experiment

Heat Input		Thermocouple Readings					
(w)		Ta (Two samples)		Tb (Two samples)		Tc - Infill Material (Two samples)	
V	I	T1 (a)	T2 (a)	T3 (b)	T4 (b)	T5 (c)	T6 (c)

5.7. Calculations

Have to Obtain Rt (R-value)

Rate of heat Supplied (W = I/A)

Heat flux (heat per unit area) q = W/A

Thermal Resistance per unit area (**R-Value**) is (Temperature difference between surfaces) / Heat flux) = **(Tb – Tc)/q**

5.8. Result:

The Theoretical U - Value of the material -
The Experimental U - Value of the material -

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