FABRICATION OF CELLULOSE FIBER FOR THERMAL INSULATION USING PAPER WASTE

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE
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MASTER OF TECHNOLOGY
IN
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Submitted by:

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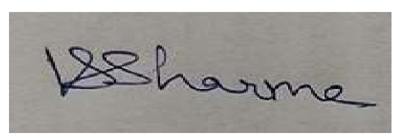
I, Vijay Shekhar Sharma, Roll No. 2K18/THE/121 student of M.Tech. (Thermal Engineering), hereby declare that the dissertation titled "Fabrication of Cellulose Fiber for Thermal Insulation Using Paper Waste" which is submitted by me to Mechanical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.



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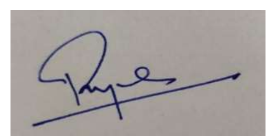
CERTIFICATE

This is to certify that this dissertation report entitled “Fabrication of Cellulose Fiber for Thermal Insulation Using Paper Waste” being submitted by Vijay Shekhar Sharma (Roll No. 2K18/THE/21) under the supervision of Prof. Rajesh Kumar, Mechanical Engineering Department, Delhi Technological University, New Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology.



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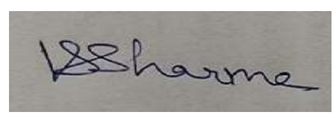

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ABSTRACT

Cellulose fiber Insulation is a supportable material for the purpose of Thermal Insulation processed from recycled paper. It tends to be installed over wall by the means of cellulose tile. Cellulose fiber insulation is an Eco-friendly thermal insulation material which is also economical to use considering the source, reused paper. The great thermal properties and low embodied energy make it desirable eco-friendly material. Anyway because of absence of good knowledge in its application and properties, cellulose insulation isn't generally utilized in contrast with more conventional insulation materials. Considering the reasonable energy saving method for structures, outer wall insulation framework is required to assume a significant function in building electricity conservation. Also, higher energy efficiency drives our requests for a lot thicker thermal insulation materials. The thermal properties of cellulose fiber insulation was resolved utilizing the simulation work over the Ansys software. Cellulose insulation simulation were created with fluctuating thickness. Similarly, simulation were done with different insulation material EPS for comparative results. The result have shown that the performance of cellulose insulation was significant towards its counterparts. The comparison with the material of similar properties have shown that cellulose fiber insulation is better in thermal conductivity. The cost analysis of the material have shown that cellulose fiber insulation have similar result or little bit lesser then its counterpart, but have potential to improve if the scale of production is increased significantly. The work is to improve the insulation quality by the method of cellulose tiles which fasten up the other cellulose fiber insulation method and provide better insulation and reduce the disadvantages in other method.

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LIST OF SYMBOLS AND ABBREVIATIONS

CFI	Cellulose Fiber Insulation
EPS	Expanded polystyrene
XPS	Extruded Polystyrene
HDD	Heating degree day method
CDD	Cooling degree day method
PWF	Power work Factor
$q_{a,h}$	Heat Flux for wall
R- value	Heat Resistance
h_i	Inner convective heat transfer coefficient
h_o	Outer convective heat transfer coefficient
U	Overall Heat Transfer Coefficient
r_c	Critical Radius Of Insulation
r	Radius Of Insulation
η	Efficiency of Equipment
K	Thermal Conductivity
C	Thermal Conductance
T_{avg}	Average Temperature
x	Thickness Of Insulation
Ø	Heat flux (W/m2)
Ƿ	Density (kg/m³)
c_p	Heat capacity at constant Pressure (J/kg·K)
ΔT	Difference in Temperature (K)
v	Velocity (m/s)
α	Thermal diffusivity
β	volume thermal expansivity (sometimes denoted α elsewhere)
T	Temperature
$Ø_q$	Heat flux
€	Emissivity (unity for a black body)
F	View factor between two surfaces a and b

T_a & T_b	Absolute Temperatures (in Kelvins) for the two objects.
C_{total}	Total cost of the material
C_{ins}	Cost of insulation material
C_{int}	Cost of installation

CHAPTER 1
INTRODUCTION

This chapter discusses cellulose insulation pad that has significant role in application like wall insulation of building, factories and in transport medium and the small and big vessels.

1.1 motivation

Usage of renewable material on various heat conserving medium has attracted various industrial and commercial application due to their virtue of least pollution and sustainability. Since these material are available in environment and easily accessible, it is necessary to utilize them in order to become less dependent over synthetic material. In order to improve over ecosystem and lower pollution level, an alternative eco-friendly insulation is needed. On the market of thermal insulation materials, the main products are synthetic that are mainly produced from fossil fuels and because of their high demand the environment concern has been growing. Therefore, thermal insulation in buildings, factories, vehicles and utensils has been an important objection for the global sustainability and the care of environment and human life. The various resource used in thermal insulation are like styrene, polystyrene, etc. they are widely used in thermal insulation applications. These material have good thermal properties but on the other hand are not environment friendly. These material when are disposed remain stranded into the environment for very long duration. Which is very harmful seeing the current scenario of waste produced daily.

There is need of usage of material which could lower the rate of waste production as well as environment friendly. The use of agricultural waste and paper waste in the thermal insulation is the topic that is hot among the researcher. These material not only try to solve the waste problem but also are efficient thermal insulation.

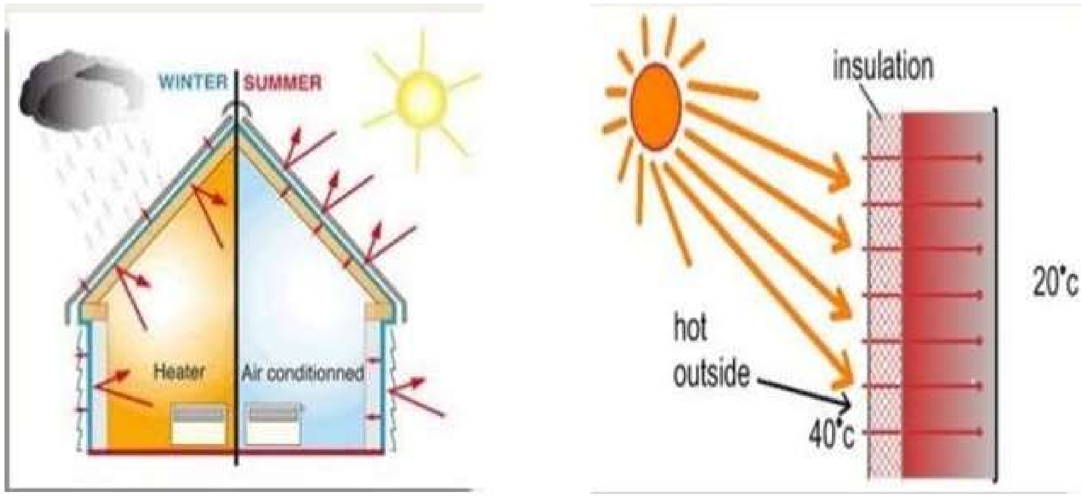

Fig. 1.1 Example of residential insulation in the home.

As, the need of the in thermal insulation is very much essential in our life. The basic need of insulation arises as from the point of the view that humans are warm blooded mammal, which requires it to maintain to a certain amount of body temperature for the proper body functioning. This is also similar to various other mammal spices which use different kind of natural insulation to keep their internal temperature at a set range. This heat to maintain the body temperature is generated by the internal mechanism of the body. The work of thermal insulation arises to maintain this internal heat and to minimise the loss of heat to surrounding. Naturally we are developed with the limited amount of insulation which could facilitate our need for range of temperature like, body hair, fat, hard shell. But, as we live in diverse environment with different temperature all year round, we require an external mode of thermal insulation. We can also base that the permanent settlement of human spices rely in the efficiency of the insulation that we had. Thermal insulation is one of the building block of the humanity. In some application the use of thermal insulation is not limited to the restriction of the flow of heat but it also provide protection surrounding environment. The better are our insulation the more places we can go to explore the definition of the universe. Each building speculation is related with the development of created environmental weights in types of various discharges and (contingent upon sizes of ventures) financial expense. Thermal protection (or thermal insulation) of a structure office doesn't generally turn into a good monetary and environmental arrangement. In the event of utilizing basic material with high warmth obstruction it is conceivable to turn out that the utilization of extra thermal protecting material can be monetarily and environmentally uncalled-for[1,2]. For the financial evaluation of a thermal insulation speculation appropriately adjusted markers were proposed: net present worth, profit pointer and compensation period. Most exploration on cellulose insulation centres on the free fill application [3]. The impact of adsorbed moistness on thermal conductivity on free fill cellulose fibers has been examined. A direct connection between dampness substance and thermal conductivity has been set up [3,4]. These examinations consider just the impact of stickiness contained inside the free fibers, and not how drying of filaments can impact these properties. It has been indicated that once paper filaments dry, their quality expands, porosity diminishes, and their dampness maintenance limit diminishes. These adjustments in the fiber structure during drying can lessen the material's porosity, in this way possibly influencing the thermal conductivity of cellulose insulation. Cellulose fiber insulation can be used vividly across structures as their properties are beneficial to both environment as well as financially. The ecological effects are diverse relied upon the kind of the exterior framework, the insulation materials utilized and the area of the structure while dissecting the entire life pattern of the structure. Researcher looking at changed insulation types frequently show a bit of leeway for the EPS or styrene put together insulation with respect to other insulation types because of low material utilization and weight in most ecological effect classifications. Some likewise contemplated the natural effect of inventive materials as cork, flax filaments or plant determined epoxy sap. . Next to the ecological effect the monetary markers of the insulation materials are here and there examined. Studies reason extra indicators that assess the speculation sway from the environmental perspective. Insulation types utilized in outer warm insulation impact the structure of the outside warm insulation frameworks. For instance, EPS insulation requires less render than delicate insulation. This likewise influences the natural impression of the framework. The natural fibers can not only be used for the insulation of walls but to create the artificial structures that can temporary stand and provide sturdy home. These innovation can make this to help the poor structure for economically weaker people thus giving them a more proper living standard. The ability to adjust as well to provide the strength could help in securing a stable shelter. The portability of this light structure could also help in transporting to remote areas, where the shelter is in the form of tent usually made from canvas. The thermal properties of the cellulose fiber could help in shielding the structure from cold as well as hot climate. The use of natural material would also ensures the protection of environment and the decomposition of the forsaken structure.

The motivation of this dissertation is to fabricate the cellulose fiber for thermal insulation which could be used for the padding of the internal wall of the building as a square pad, it can be used to build temporary structure for living. The proposed the thermal insulation material is advantageous for both economically and environmentally over conventional methods. They have straightforward structure and give simpler administration. Thus, a cellulose fiber thermal insulation is discussed in this dissertation.

1.2 Literature Review

Thermal protection materials are a basic aspect of a structure envelope. They ensure that keeping the room temperature within the preferred range, let go the need to either cool or warm the room which in fact lowers the consumption of electricity. Exhaustion of petroleum products, fossil fuels and other non-renewable resources because of more utilization of these assets are brings about increment in oil and flammable gas costs. Increment in demand because of quick ascent in populace brings about more consumption of these resources and subsequently goes about as a legitimate purpose behind sustainable power source to come into picture. Thermal protection is without a doubt perhaps the most ideal approaches to decrease the energy consumption due to heating as well as cooling. Thermal resistive material assume an important role as electricity saving is directly proportional to the right material, its position and its thickness. Properties of insulation are critical, however, when structuring a building envelope: effect on nature, water fume penetrability, on human wellbeing, protection from fire and sound protection should be deliberately evaluated as well. [5] According to EN ISO 9229 thermal protection materials are material with thermal conductivity lower then 0.1 ($W.m^{-1}.K^{-1}$).Thermal protection is one of the best methods of sparing energy utilized for warming and cooling structures. In a moderate atmosphere, the winter in particular, the heating of inside the structure, yet in addition in passing time (spring & autumn) is noteworthy undoubtedly. Thusly, deciding and choosing the ideal thickness of protection is the principle goal of many research works [6-12]. In the twentieth century, there is extraordinary capability of essential energy saving, the utilization of which doesn't mean incredible budgetary ventures, as it happens in other developed nations. Thermal protection of building has a significantly affects the decrease of thermal energy utilization in structures that prompts the decrease of CO^2 emissions. Causing a thermal protection of a structure wall to can as far as economic perspectives be drawn nearer as a speculation. In this speculation the expense is identified with the buy, transport and laying the insulation, though the benefits are connected to the decrease of thermal energy utilization important to heat a structure. The need of improving the fiery productivity of structures regarding utilizing last energy in world outcomes above all else from a high utilization of this energy in structures themselves (about half) [13,14]. It is important to feature that thermal protection (or thermal modernization) turns into a major reducing capability of utilizing final energy in the structure division and is resolved economically as per McKinsey curve simultaneously. High utilization of energy in the structure segment in the European Union is likewise liable for the emanation of a lot of carbon dioxide into the air. Each building venture is related with the development of produced natural burden in types of various emissions and (contingent upon sizes of investment) economic expense. Thermal insulation (or thermal modernization) of a structure facility doesn't generally turn into a great economic and biological arrangement. In the event of utilizing auxiliary material with high heat resistance it is conceivable to turn out that the utilization of extra thermal insulation material can be economically and naturally inappropriate [13].

Insulation material made from bio based insulation material are novel class, these are animal based material or regular or re-newable plant based. The interest for theses material is developed considering the need of renewable material it is and recyclable and also they have less embodied carbon dioxide in them and by recycling it will also lower the carbon dioxide emission of the building. This implies their utilization in development decreases the net building’s carbon dioxide that is trapped, at times bringing about a 'negative' carbon impression.

These materials can be utilized all alone, with negligible preparing, for instance straw bunches; they can be handled to frame normal moulded units, for example, Stramit, sheep's wool orwood wool; or different materials can be joined to shape composites, for example, hemp–lime. One of the quality of the biobased material is that they are ‘vapour active’, which means that vapour could penetrate through it, however they are likewise equipped with buffer to lower the moisture and could be utilised in the thermal stores. It’s this quality which separate it from those oil and synthetic based chemical insulation material.

Bio-based insulation materials, for example, natural fiber batts, offer various advantages in examination with more settled mineral and oil-based other options, for example, polyurethane rigid foam (PUR)-and mineral wool based element. New sourcing of the focus point gives a good renewable chain and have a impression of decreased carbon through the photosynthesis the negative carbon footprint of plant based material. A customary block and brick residential home contain 100 $kg.m^{-2}$ carbon dioxide and proportional to wall development's emissions [15] .A house which is lined with hemp lime has 35 kg/m^2 CO^2 embodied in the wall development. A normal home contain about 80 m^2 of external wall, which, whenever developed from hemp lime, would leave 10.8 ton CO_2 and comparable emissions in embodied energy.

The thermal insulation of bio-based insulation materials is commonly sub-par compared to that given by chemical and particularly stiff foam insulation material. Although essentially expanding the need of increased insulation thickness in wall will rule this, as the carbon footprint increase, the pressure over the land and building worth will be joined. Not with standing, bio based insulation materials display different profitable attributes that, if ready to be perceived in configuration, artificial materials to be placed in front. Bio based insulation materials, for eg., hemp lime, are water absorbant[16] demonstrated that in a hemp lime divider (U-value 0.44 $W.m^{-2}$ .K) 17 percentage energy is passed compared with 75 percentage for a wall made of mineral wool (U-value 0.14 W.m-2 .K) more than twenty four hour when exposed to an at once drop in temperature.

The main objective of applying thermal insulation materials in a structure wall are to forestall heat loss and give thermal solace to a structure's inside. The factor that tells about an insulation material's compatibility is its thermal conductivity k (estimated in $W.m^{-1}.K^{-1}$). The lower thermal conductivity of a material better its chances of as an insulation material and less thickness would be needed to maintain the similar range of temperature. Traditional material used for insulation incorporate stone fleece, glass fiber, extended polyurethane foam and polystyrene. As, these materials are good and productive in maintaning the heat for thermal comfort inside the structure, non-inexhaustible material is used to make them & has high epitomized energy. Therefore, the increasing enthusiasm for elective insulating materials that originate through supportable or reused paper. Characteristic strands, for example, jute, flax and hemp have demonstrated to be appropriate options in contrast to mineral insulation & are the subject of various exploration ventures [21].

With globalization and populace blast, increment in paper utilization has brought about enormous measure of paper-related waste. It has been discovered that 25–40% of metropolitan strong waste created every year overall is paper-related [17]. The enormous mass of waste causes woodland decimation, trouble for removal just as environmental contamination. Subsequently, it is critical to reuse or change over this colossal waste into valuable items. There have been a few endeavours in tackling this issue. For example, 63% of paper squander was reused in the USA in 2010 [18]. Paper waste has likewise been examined as a crude material for the creation of bioethanol, polymer antecedents, particleboard, and so forth [17,19,20].

The ecological effects are distinctive relied upon the kind of the façade framework, the insulation materials utilized and the area of the structure while breaking down the entire life pattern of the structure [23]. Explores contrasting diverse insulation types frequently show a favourable position of the EPS or styrene put together insulation with respect to other insulation types because of low material utilization and weight in most ecological effect classifications [24]. Some likewise examined the natural effect of creative materials as cork, flax fibers or plant derived epoxy resin [25]. The majority of the investigations center on the support to-entryway stage. Close to the natural effect the economic markers of the insulation materials are at times considered. Studies reason extra markers that assess the venture sway from the biological perspective [26].

Cellulose insulation for use in building applications is principally fabricated from reused newsprint or cardboard utilizing shredders and fiberizes. Cellulose insulation as an item is around 80 wt. % cellulosic fiber and 20 wt. % synthetic substances, the greater part of which fire retardants, for example, boric corrosive are and ammonium sulfate [27]. Cellulose fiber insulation is essentially made out of shredded paper introduced with inorganic added substances that go about as fire resistant & shape development inhibitors. Cotton wool has similar consistency when felt. Reused paper is generally used as source material to make cellulose fiber, which usually come from not used or recycled papers. Newspaper is generally made from mechanical mash. Reused newspaper or concoction mash would be combined. Likewise with most lignocellulose strands, newsprint is contained a blend of cellulose hemicelluloses & lignin. As a last item, CFI could be divided in two form: as a pre-assembled board, in which the cellulose filaments are moulded into with polymer cover or, all the more regularly, the free strands are sold in mass structure to be physically applied on upper rooms, roofs, or dividers. In this paper, the utilization of cellulose fiber in the normal family unit. We will learn about the way toward setting up the insulation cushion by the utilization of cellulose fiber, eliminating a portion of its faults like combustibility, hygroscopisity and contagious development [28]. The economical and natural parts of the basic family unit, the utilization of energy without insulation [26]. The water ingestion properties of the cellulose fiber. The cushion will be set up by the utilization of form and pressure which will eliminate the additional dampness and afterward will be sun-dried to make it completely dry. To make it flame resistant the utilization of borate salt to forestall ignition and boric corrosive is utilized to forestall seething [29,30], and diminish its dampness ingestion properties. The exploratory examination will be finished by the utilization of empty 3D shape of the mass of cellulose cushion with a warmth source and the temperature noted at various time span. The thickness of the cellulose cushion will be shifted by the basic thickness of the material and the economic variables. The diverse temperature esteems would be appeared on the diagram. This will show the viability of the cushion and its insulating properties. In spite of the fact that the run of the mill an incentive for Cellulose Fiber Insulation's thermal conductivity(k) is around 0.040 [$W.m^{-1}K^{-1}$], its properties and execution can fluctuate marginally relying upon assembling and technique for establishment. [39]has indicated that a distinction in the source material newspaper quality can have significant impact on thermal execution. In experimenting, CFI tests taking place from USA and Korea were estimated with help of warmth stream meters. By highlighting over Cellulose Fiber Insulation from the 2 countries, the investigation that took place concluded that the Korean filaments that are smaller as because to having experienced additionally reusing measures show a g eater cost saving for thermal conductance, and accordingly lower insulating execution than Cellulose Fiber Insulation strands from the USA. Since cellulose strands are normally water absorbing, dampness ingestion can likewise influence thermal conductivity esteems[40]. Thermal conductivity estimations were made on introduced tests watched hot container method with an average temperature of 15 °C and a temperature compared of roughly 10 °C. It was discovered that thermal conductivity expanded by 15percentage for a dampness addition of 10percentage [41] found that under the vapour absorbing range (RH <90%) the adjustment in thermal conveyance of loosely fill cellulose Fiber inside a wall cavity was not huge(1%–3% expansion). The investigation was done on veneercomponents with 285mm free fill Cellulose Fiber Insulation outfitted with heat stream tester and dampness estimating dowels. Warmth stream estimations were made by the DS418 norm [42] created three ways to deal with decide thermal conductivity as a component of water assimilation utilizing dampness content profiles of CI. Estimations were made on 164mm thick free fill Cellulose Fiber Insulation tests on 600mm × 600mm outlines, following the ISO8301 and ISO DIS10-051 norms. PC recreations utilized the accompanying connection concerning the thermal conductivity of cellulose fiber insulation:

$$\lambda=0.0037+0.0003x(W.m^{-1}k^{-1}) \quad \text{………. (1.1)}$$

Where x is the density of cellulose [$kg.m^{-3}$]. The determined outcomes were in concurrence with test estimations [43] decided a polynomial capacity to portray the connection among moisture and thermal conductivity to bend putting the qualities estimated by a heat flow meter contraption as indicated by ASTM standard C518 over cellulose material at various conditions. Temperatures that were to be estimated were put at 10 °C and 350 ºC, with a base of 22.5 °C The main exploration that contemplated changes in thermal conductivity past the water absorbing limits was finished by [44] Their investigation decided dampness substance of Cellulose Fiber Insulation in one - and two floor structures with workmanship dividers with many range for thickness of insulation all through different dampness periods estimations. A subjective technique was utilized to decide the impact of dampness on varieties in thermal conductivity. An increase in 1 percentage of dampness substance can prompt a normal difference of 1.2%–1.5% in λ values for loose-fill Cellulose Fiber Insulation. In any event, when large dampness content was reached, thermal conductivity increased from 1.6 to 2.0% for 1% of dampness content. These changes in testing of λ are like those referenced already in the hygroscopic range. The thermal conductivity that is increase could be viewed as unimportant, for the most part of hygroscopic range. Just as when narrow dampness starts (RH > 90%)where the insulating properties would be insufficient. downpour invasion, spilling pipes, or inappropriately introduced wet splash cellulose could be the reason for such cases.

1.3 Research Objective

The aim of this study is to show the method of improving the insulation of the buildings by the use of renewables material in the cost effective way. The research conducted during the time frame was to utilise the waste paper material to be used as heat resistance material in the commercial buildings and homes. To use cellulose fiber pad as the insulation material in the modern day structures.

In the view of present scenario the insulation that is vividly used in the structures in synthetically formatted from non-biodegradable material which although perform its stated function but create a burden over the environment, but the presented cellulose fibre insulation pad while providing the comparable insulation is also fabricated from the recycled from the paper waste and is biodegradable. Specifically, this work include:

1. Structure design and analysis of the cellulose fiber insulation from the waste paper material.
2. Comparison between the existing insulation and the cellulose insulation. And the analysis of the properties.
3. Different controlled simulation over the Fluent Ansys to know the result for the comparison between the existing insulation and the optimal thickness required for the fabricated insulation.
4. Fabrication of the insulation pad from the proposed raw material and testing of its properties.

1.4 Research composition

The dissertation is organized in four parts. The first part consists of Chapter 1, which gives an outline about the literature review on the developments related to cellulose fiber insulation. The motivation, aim and objectives for pursuing the research has been described here.

CHAPTER 2
EXISTING INSULATION TECHNOLOGIES AND MATERIAL

This chapter discusses various insulation used in structures based on their application. Their structure, thermal properties, fabrication and environmental impact are presented in analysed in detail.

2.1 Overview

Structure envelope have thermal insulation as their primary need. They guarantee that within a range of temperature for a room would forfeit the need of using heating and cooling, which require high energy[31]. it could be said without a doubt that Thermal insulation is perhaps the most ideal way to decrease the need of energy due to both summer cooling and winter heating. The role played by insulation material is significant as the right material to be chosen should have, its depth and location, permit to acquire great indoor thermal solace conditions and satisfactory fuel reserve funds. Thermal properties are critical, however they are not by any means the only viewed as when a structure envelope is planned: acoustic insulation, protection from water vapour penetrability, fire and nature's effect and wellbeing of human should be painstakingly evaluated as well. As per EN ISO9229 thermal insulation materials will be those materials that have thermal conductivity below 0-1 $W.m^{-1}K^{-1}$.

Kinds of protections: There are various rules how to sort warm protections [32]:

a) Sort of the earth substance – inorganic, natural.

b) Build - sinewy, permeable (froth), granulated.

c) Fastener content - containing folio, cover free,

d) Shape of item - free (inlay, fleece), level (board, tangle, felt)

e) Fire's reaction - non-burnable, restricted instability, ignitable

As indicated essentially of the material warm protecting items can be partitioned to :

a) Light silicate substances – light total, light concrete,

b) Foam inorganic substances – froth glass,

c) Foam natural substances – froth plastics,

d) Fibrous substances – glass fleece and mineral (stone) fleece

e) Organic substances – plug, lumber fleece, paper.

Almost Each type of available thermal insulations has its own preferences and demerits. Decision of the privilege insulating material ought to consistently consider kind of the structure development and conditions in which it will serve. Because of its wide-spread and complex highlights. [33] We can discover these days various insulations. To isolate them, there are two gatherings, conventional insulations and current insulations. The insulations those has been in use from the early construction are the Conventional insulations and they are still used in various construction projects, and they are Polystyrene broadened, Polystyrene removed, Fiberglass, Polyurethane, Rock fleece. Present day protections are ones that doing a few tests during this occasions are likewise productive or more than the customary, and the vast majority of them are common or with scarcely any effect in the earth are Fiberglass,Rock fleece,Cellulose,Aerogels Straw parcels.

Among many Form of insulation that is used some are most commonly used in the buildings like polystyrene, polyurethane, fiberglass, wood wool, cork , etc. these insulation will further be discussed in the detail will be basis for the comparison in this dissertation.

2.2 Polystyrene

The polystyrene insulation is normally utilized in the structure. It is full between the walls to give additional heat obstruction from outrageous climate. There various sort of the polystyrene that pre-owned they are Polystyrene extended, polystyrene extruded.
The EPS and XPS industry holds a piece of the pie of 35% of the absolute insulation market for development. In the recent time they have been maintaining there status with well their us usage. polystyrene is an engineered sweet-smelling polymer produced using the expandable polystyrene is made up of embellishment dabs of cell plastic material that are not flexible monomer styrene or copolymers and which have a significant shut cell

structure, that has air in between [34]. it can be both strong or frothed. Polystyrene that is widely used has lightweight, hard, clear, and rather fragile, shut cell froth. It is a reasonable tar for each unit weight. It is a fairly helpless hindrance to oxygen and water fume and has a moderately low softening point. Polystyrene is one of those plastic which is most commonly used, the amount which is created could be calculated in few crore kilogram per year. Polystyrene can be normally straightforward, however can be hued with colorants. Extended polystyrene (EPS) is usually utilized in an assortment of uses due to its highlights of fairly less weight, great warm protection, dampness opposition, toughness, acoustic retention and low heat resistance. It has been progressively utilized in building developments as center material of auxiliary protected boards. A portion of those structures during their administration life might be exposed to dynamic-loads, for example, unintentional or unfriendly blast loads and windborne garbage impacts. The dynamic material properties could be understood of EPS is basic for dependable forecasts of the exhibitions of the basic protected boards with foam center material.

Extruded froths are made by blending the polystyrene in with a dissolvable, including a gas under tension lastly expelling the blend to the necessary thickness. The expulsion cycle improves the attributes of the last froth, for example, its mechanical resistance, giving more similar material and not internally connecting pores. The mechanical resistance of broadened polystyrene froths can move from 0.4 to 1.1 kg/cm2. There are a couple of assessments of froths available with densities from 10 to 33 kg/m3, with warm conductive that are below with the expansion in thickness, as showed up in Table 2.1.Thermal property is estimated by EN 12667 and ISO 13163, ISO 12939. Run of the mill esteems run from 0.032 to 0.038 [W/mK] relying upon the thickness of the EPS board. The estimation of 0.038 [W/mK] was acquired at 15 [kg/m^3] while the estimation of 0.032 [W/mK] was gotten at 40 [kg/m^3] as indicated by the information sheet of K-710 from StyroChem Finland. [31]. EPS conduct with fire is at any rate rapidly for his plastic structure, yet in addition have retardants to change his season of consumed and smothering. In spite of the fact that it is a shut cell froth, both extended and extruded polystyrene are not so much waterproof or vapour proof. In extended polystyrene, water ingestion will be resolved as per ISO 2896 there are interstitial holes between the extended shut cell pellets that structure an open organization of channels between the fortified pellets, and this organization of holes can get filled with fluid water. On the off chance that the water freezes into ice, it grows and can make polystyrene pellets sever from the froth [34]. Disposed of polystyrene doesn't biodegrade for many years and is impervious to photolysis, non-reusing and non-cremation.

Type	Density	Thermal conductivity
	(kg/m³)	*(W m⁻¹ °C⁻¹) / (kcal h⁻¹ m⁻¹ °C⁻¹)*
Expanded foam Type I	10	0.0570/0.049
Expanded foam Type II	12	0.0440 /00.038
Expanded foam Type III	15	0.0370/00.032
Expanded foam Type IV	20	0.0340/00.029
Expanded foam Type V	25	0.0330/00.028
Rigid extruded foam	33	0.0330/00.028

Table 2.1 Thermal conductvity and density values at 0 °C of polystyrene insulation [35] [37]

2.3 Polyurethane

Polyurethane foam is successful as a protector since the good amount of(90% least) of non-associated shut microcells, filled with idle gas. As of not long ago, the idle gas most usually utilized in polyurethanefoams wasR-11(trichlorofluoromethane). In any case, the Montreal Protocol on Substances that Deplete the Ozone Layer has required the eliminating of the utilization of CFCs, for example, R-11. Substitution foaming specialists are being examined right now, with hydrocarbons, hydrofluorocarbons and idle gases, for example, carbon dioxide being created as substitutes. The primary ways polyurethane foams can be applied and utilized are as inflexible sheets/chunks and pre-framed lines, which can be made in different shapes and sizes. The primary uses of these sorts of foam are in chill rooms, ice stores and cold stores. Basic sandwich boards fusing pieces of foam can be created for pre-assembled refrigerated stores. It might be discovered important to eliminate the cladding from the foam. On the off chance that any welding or other activity including bare blazes or high temperatures is to be completed, the foam must be scaled back to at any rate 1 ft. (0.33 m) from the site of activity. All uncovered foam must be secured (for example with an asbestos cover) from the stripped flares or high temperatures. Poisonous perils emerging from consuming foam in the same manner as wood, fleece, plumes, and so on the results of ignition of polyurethane foam and different plastics are risky. On account of fire, the typical perils, for example, absence of oxygen, thick smoke and hot gases are available and ordinary putting out fires drill ought to be watched. A defensive coating ought to be fused to make the foam harder to light from a little wellspring of fire. Lab tests show that unprotected (inflexible) polyurethane foam containing a fire-retardant won't light from little fire sources, for example, matches, yet will consume quickly when presented to enormous wellsprings of fire and heat.

A few evaluations of polyurethane foams are accessible, including grades that are especially fireproof. These foams, which contain isocyanurate, can make due for 10-25 minutes before consume happens. Financially accessible isocyanurate foams have a normal thickness of 35 kg/m^3, thermal conductivity of 0.022 kcal/hm °C and permeance to water fume of 16.7 g cm /day mmHg.

2.4 Fiber glass

Fiberglass tangling is likewise utilized as protecting material and offers the accompanying favorable circumstances:

- Good amount of insulation to fire;
- Good amount of insulation to microorganism attack;
- High resistance to chemical;
- Highly insulative material;
- Comes in no. of other variety
- high thermal resistance (see Table 2.2).

Type	Density	Thermal conductivity
	(kg/m3)	(W m-1 °C-1) / (kcal h-1 m-1 °C-1)
Type I	010-018	00.044/0.038
Type II	019-030	00.037/0.032
Type III	031-045	000.034/0.029
Type IV	046-065	00.033/0.028
Type V	066-090	00.033/0.028
Type VI	091	00.036/0.031

Glass fibre, resin bonded	064-0144	00.036/0.031

Table: 2.2 Thermal Conductivity and Density Values At 0 °C of Fibreglass Insulation [36][37]

Fiber glass insulation is accessible in moves of various thickness, additionally called covers and tangles. The width of the covers and tangles will rely upon the manner in which they are to be introduced and some come looked on one side with foil or Kraft paper, which fill in as fume hindrances. Be that as it may, the fundamental specialized restrictions of fiberglass tangling as insulation seem to be:

- low strength of structure or be able to compress easily;
- It tends to set down after installing if not done properly.
- The water penetrates through it easily.

Inflexible board boards can be made with packed fiberglass. These lightweight protection sheets have moderately high Resistance-values to their width.

2.5 Cork

Cork is presumably among the most established insulating elements utilized monetarily, and if we look to the past it was among the most used material for refrigeration. Now, because of the shortage of cork-creating trees, its cost is generally high in correlation with other insulating materials. Consequently, its utilization is restricted, except for some machine establishments to diminish the transmission of vibrations. It is accessible as extended pieces or sheets just as in granular structure, its thickness changes from 0110 to 0130 kg/m^3 and it has a normal mechanical obstruction of 02.2 kg/m^2. The working should be near 65°C. It has great thermal insulating adequacy, is genuinely impervious to pressure and is hard to consume. Its principle specialized restriction is the propensity to assimilate dampness with small permeability of moisture of 12.5 g.cm.m-multi day^{-1}.mmHg^{-1}.

Type	Density (kg/m3)	Thermal conductivity (W m-1 °C-1) / (kcal h-1 m-1 °C-1)
Granulated loose, dry	0115	00.052/0.0447
Granulated	0086	00.048/0.041

Expanded cork slab	0130	00.04/0.344
Expanded cork board	0150	00.043/0.037
Expanded bonded with resins/bitumen	0100-150	00.043/0.037
Expanded bonded with resins/bitumen	0150-250	00.048/0.041

Table: 2.3 Thermal Conductivity And Density Values At 20-25 °C Of Cork Insulation [36][37]

2.6 Differentiation between various insulations

A portion of the more normal materials utilized for insulation are contrasted in Table 2.4 and the comparative resistance value and the focal points and detriments of specific sorts. All in all, the more costly materials, for example, the polyurethanefoams are more productive separators for mentioned width. Utilizing the "R" arrangement of evaluating (see definitions in Appendix A) it is conceivable to show up at comparable "R value" for an assortment of insulating material sorts. Figure 2.1 shows the examination of ordinary thicknesses of various insulation materials utilized for chill rooms and ice stores, working on shore, in mild and tropical territories, at normal surrounding air temperatures of 20, 30 and 40 °C. A few architects demonstrate that conductive coefficient l for ought not surpass 00.260 kcal/m^2h°C (proportional to a R-esteem = 18.8 ft^2 h °F Btu^{-1}). In any case, the setting of this worth relies essentially upon the energy costs, subsequently it might be decreased if, later on, energy costs increase.

Insulating material	"R" value per inch	Advantages	Disadvantages
Polyurethne, board	6.250	Good value of R	Difficult to find them and may be expensive
Polyurethne, spray on	7.00	The value of R is better, could be taken for use in fiberglass, easy application	Not always easily available, expensive, requires special spray equipment

		with spray equipment	
Polystyrene, sheets (smooth) "Styrofoam"	5.00	Easily available. Cheap, average R-value	Could not be utilized with fiber glass unless sometype of protection is used, easily damaged
Polystyrene, foamed. Known as Isopor, Polypor, etc.	3.750 to 4.00	Reasonable R-values, lower cost than smooth surfaced sheets	Could not be utilized with fiber glass unless sometype of protection is used, easily damaged
Cork board	03.33	Availability in many markets, reasonable cost, can be covered with fibreglass	Lesser value of R than styrene foams
Fibreglass wool	03.3	Low cost, ease of installation	High water absorptions, loses insulating value when wet
Wood chips	02.2	easily available, cheap	Absorbs moisture and loses R-values when wet, decays
Sawdust	02.44	easily available, cheap	Absorbs moisture and loses R-value when wet, packs down under vibration
Straw		easily available, cheap	Absorbs moisture and loses R-value when wet, host to insects, etc.

Air	1.00 approx.	No cost	Has to be completely sealed to prevent air circulation causing heat infiltration

Table: 2.4 Insulating Materials, "R" Values, Advantages And Disadvantages [36][37]

The determination of the ideal insulation thickness for wall will rely upon components, for example, the insulation costs (materials and establishment), energy cost, yearly cost investment funds in cooling because of improved insulation productivity, and nearby conditions. Along these lines, the ideal thickness of insulation ought to be chosen on an individual area. Nonetheless, considering the nearby natural conditions where the dangerous atmospheric deviation is factor. In practice, still there is need for balance to be made between the ideal cost effective insulation thickness and the cooling costs. It is likewise significant, for arranging purposes, to contemplate the warmth generated due to conduction & radiation which effect the overall thickness for insulation.

CHAPTER 3
CELLULOSE FIBER INSULATION PROPERTIES AND ECONOMIC AND ENVIRONMENTAL BENEFITS

In this chapter, cellulose fiber insulation is discussed in detail. In this the properties of cellulose fiber is discussed and how it could be utilized for insulation. The method required to calculate the thermal conductivity of the material and the optimal thickness of the insulation will be shown. This chapter also discusses the various way to utilize the raw material to be used as insulation and why the prefabricated insulation pad is better than other method of application. The economic and environmental benefits due to thermal insulation of building external walls using cellulose fiber insulation are also discussed in this chapter.

3.1 Cellulose

Cellulose is a natural compound with the recipe $(C_6H_{10}O_5)_n$, a polysaccharide comprising of a direct chain of a few hundred to a huge number of β(1→4) connected D-glucose units. Cellulose is a significant basic part of the essential cell wall of green plants, numerous types of green growth and the oomycetes. A few types of microbes emit it to shape biofilms. Cellulose is the most plentiful natural polymer on Earth. The cellulose substance of cotton fiber is 90%, that of wood is 40–half, and that of dried hemp is roughly 57%.

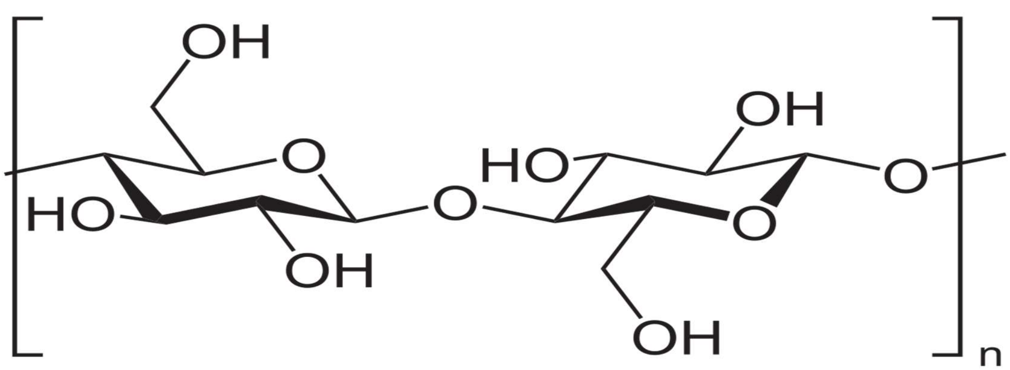

Figure: 3.1 Cellulose, a linear polymer [38]

3.2 Cellulose fiber insulation

Cellulose insulation has been a time tested technique for insulating homes for quite a long time. It is produced using reused paper with probably the most elevated level of post-buyer squander substance of any insulation. It is treated with perceived safe fire retardants. Its phenomenal sound insulating properties, high R-value per inch, and industry driving natural properties, settle on cellulose insulation an ideal decision for insulating upper rooms and sidewalls. It is a fantastic decision for including insulation in walls of more seasoned existing homes because of the simplicity of establishment.

3.2.1 Advantages and disadvantages

The cellulous insulation's properties has its own advantages and disadvantages [28].

Advantages:

1. Thermal performance:

The loose filled cellulose shows thermal qualities that looks at well to different kinds of minimal effort insulation, but, it has lesser values when compared to that of polyurethane and polyisocynurate foams. The value of thermal conductivity for loosely-fill cellulose comes out to be roughly 0.040 $W.m^{-1}.K^{-1}$, which seems to be equivalent to or marginally superior to glass or rock wool. This doesn't speak to the entire image of thermal execution.

2. Long haul cost reserve funds:

Annual investment funds from insulating fluctuate generally and rely upon a few variables, including insulation thickness, unique wall execution, nearby atmosphere, heating/cooling use, impenetrability of other structure components, etc. One installer claims cellulose insulation "can spare mortgage holders 20 to 50 percent on their service bills"

3. Sound insulation:

Cellulose gives mass and damping. This diminishes commotion in 2 different ways, it decreases the sidelong development of sheetrock and constricts the entry of sound along cavities. Cellulose is around multiple times denser than fiberglass, giving a slight improvement in sound decrease.

4. Mold and pest control:

The borates in cellulose insulation give included control against shape. Establishments have indicated that even a while of water immersion and ill-advised establishment didn't bring about shape. The properties like bug control cannot be given by just adding borates it's a typical myth. While boric corrosive itself slaughters self-prepping bugs whenever ingested, it must be introduced to a bug in both adequate focus and in an ingestible structure so as to accomplish creepy crawly casualty

5. Fire resistance: The highest fire safety rating could be achieved by the borate treatment. A blend of ammonium sulfate and borate is used by many companies.

6. Moisture penetrability: The wall filled by insulation depression totally, (for example, cellulose or foam) can help forestall dampness issues. Suggestions against utilizing fume hindrances with cellulose insulation are upheld by contemplates, despite the fact that they arrange cellulose as fume porous. [29]

Demerits:

1. Weight: the amount of cellulose would be up to three times when compared to fiber glass in terms of weight.

2. Shape: There is some proof of increased form invasion inside structures protected with wet shower thick pack cellulose particularly when utilized with a fume hindrance.

3. Dust: The small particles in cellulose can pass through the house from loose seals or small holes.

4. Off gassing: Numerous type of cellulose organizations utilize a blend of ammonium sulphate and borate for fire hindrance. In spite of the fact that ammonium sulphate is typically unscented, unexplained towards the outflow of alkali and a subsequent alkali smell could be seen sometimes.

5. Slumping: If inappropriately introduced, loosely-fill cellulose would tend to settle after applying. In certain circumstances this would leave territories of wall empty. With right amount of preparing in establishment strategies and maintaining quality control methods this is done by introducing to tried densities forestalling any future settlement.

3.3 Method of calculation

An insulating material's protection from conductive heat stream is estimated or evaluated regarding its thermal opposition or R-value - the higher the R-value, the more noteworthy the insulating adequacy. The R-value relies upon the kind of insulation, its thickness, and its thickness. The viability of an insulation material's protection from heat stream additionally relies upon how and where the insulation is introduced. For instance, insulation that is packed won't give its full evaluated R-value. The general R-value of a wall or roof will be to some degree not the same as the R-value of the insulation itself since heat streams all the more promptly through studs, joists, and other structure materials, in a marvel known as thermal crossing over. Likewise, insulation that fills building pits thickly enough to diminish wind stream can likewise decrease convective heat misfortune.

The standard unit used to portray insulating value is an R-value, a material's capacity to oppose the progression of heat through it. The higher the R-value, the better the insulating capacity of the material. 1/R is a proportion of the measure of heat energy in British Thermal Units (BTU's) that would go through a bit of material 1 square foot in region in 1 hour when the temperature is 1o Fahrenheit higher on one side of the insulation than on the other.

$$Heat\,\frac{loss}{gain}\,in\;kW = \frac{m^2 \times \Delta t}{R-value} \qquad \text{…….. (3.1)}$$

3.3.1 Heating Degree-Days Method

When all is said in done, degree day's technique is among the few of the most solid strategies for assessing the value of energy utilization in structures. Degree days technique expect that contrast in between the normal surrounding air and the base temperature (Tb) is straightforwardly corresponding to energy prerequisite of the structure. The heating-degree-days (HDD) value depicts the quantity of thickness of the temperature drop by considering the surrounding air temperature and base temperature for a given time period (month, year, and so forth.). HDD values can be communicated as follow,

$$HDD = \sum_{1}^{365}(To - Tb) \qquad \text{……… (3.2)}$$

Where T_o be the external air temperature, and T_b is the base temperature. The in addition to sign over the bracket demonstrates that only positive values should be taken, and with this the temperature should be taken as zero when To>Tb. For this study work, the base temperature, T_b was taken as 21°C.

3.3.2 Cooling Degree Day's Method

The cooling-degree-days (CDD) value depicts the quantity of thickness of the temperature drop by considering the surrounding air temperature and base temperature for a given time period (month, year, and so forth.). CDD values can be communicated as follow,

$$CDD = \sum_{1}^{365}(Tb - To) \qquad \text{………. (3.3)}$$

Where T_o be the external air temperature, and T_b is the base temperature. The in addition to sign over the bracket demonstrates that only positive values should be taken, and with this the temperature should be taken as zero when To<Tb. For this study work, the base temperature, T_b was taken as 21°C.

3.3.3 Annual Requirement of Heating Energy

A typical external wall that have a layer of insulation in between have the overall heat transfer coefficient (U) as follow,

$$U = \frac{1}{(1/h_i + R_w + x/k + 1/h_o)} \qquad \text{………. (3.4)}$$

where h_i and h_o are within and outside heat move coefficients separately, R_w is the all-out thermal obstruction of the wall materials that is without insulation, $R_{t,w}$ represents the complete wall thermal insulations barring the insulation layer, the thickness and thermal conductivity of insulation material is given by x and k respectively, individually. The yearly energy required for heating prerequisite per unit region can be communicated as follow,

$$q_{A,H} = \frac{86400HDDU}{\eta} \qquad \text{…….. (3.5)}$$

3.3.4 Calculating the Optimum Insulation Thickness and Cost Analyses

With the increase of insulation thickness, the expense for heating diminishes, while the expenses of insulations increase. Subsequently, as expense for insulation heating equipment is to be determined in order to know the ideal insulation thickness. So for this, the ideal insulation thickness is that thickness for which all the expense is a base. The expense of insulation ($C_{t,ins}$) for the outer wall can be determined as follow,

$$Ct = CinsX + Cinst \quad \text{……….. (3.6)}$$

Where, C_{ins} represent the expenditure for the insulation material as well as, C_{inst} represents the installation cost. The cost for heating C_H anuaaly for the unit surface area is given as follows

$$C_H = \frac{86400HDDC_fPWF}{(R_w+x/k)Hu\eta} \quad \text{……… (3.7)}$$

Where C_f shows the cost of fuel, H_u shows the Lower-heating value for the fuel.
PWF = present worth factor.

3.3.5 Calculating critical thickness of insulation

Here, $r = k/h_o$ represents the condition for minimum resistance and consequently maximum heat flow rate. The insulation radius at which resistance to heat flow is minimum is called the critical radius. The critical radius, designated by r_c is dependent only on the thermal quantities k and h_o. Thus-

$$r = r_c = \frac{k}{h_o} \quad \text{………….. (3.8)}$$

Following equation will be taken to calculate the various parameters in order to determine the results, there will be model prepared in ANSYS 18.2 to replicate the real life condition for the model. The model will determine the thermal resistance of the CFI varying in various thickness.

The result thus will be compared with the existing insulation material.
Application of the CFI
Cellulose fiber apart from the use as insulation for building it could be used for other purposes as well i.e.

- Cellulose fiber as the stuffing for blankets and mattresses could be a way of recycling.
- In the transport vehicle to provide extra padding and insulation to vehicle.
- In the aviation industry

- In The farmland

There also places where it could replace the potential material.

3.4 Summary of the Chapter

The properties discussed for CFI in this chapter have been considered in this work. The data used for comparison has been taken from reliable reference and mentioned. The comparison shown gives the wide view and the necessity of the present work. The calculation to be done in the result section are done with the above equations to give a significant data to support this work.

CHAPTER 4
FABRICATION OF CELLULOSE FIBER INSULATION PAD FROM WASTE PAPER

In the previous chapter, we have studied about the CFI and its properties. The use of CFI fabricated pad and its material property compared to traditional insulation material. The calculation related to the insulation and how it is both economic and environmental friendly. We have also learned in the previous chapter to calculate the life cycle analysis and heating requirement of building and how the insulation helps to reduce the energy consumption.

4.1 Overview

In this chapter, the CFI will be fabricated by utilizing the paper waste. The cost of preparing the prototype will also be given in detail. The fabricated prototype thus will be explained in detail and the dimensions will be discussed. And, also the large scale production for the same prototype thus will be laid down as well in this chapter.

4.2 Introduction

The fabrication of cellulose tile starts with the source of cellulose. Here, as the raw material is paper there is no further need for extraction of cellulose. Paper mainly consist of cellulose apart from few additives used for different quality of paper. First the making of paper, now the raw material for paper is the wood. It start with making of pulp the wooden logs are sent to grinders, which break the wood down into pulp by pressing it between huge revolving slabs. In chemical solutions the wood chips logs are cooked. Then the chips are poured into the machine called digester, and then at high pressure in a solution of Paper sodium hydroxide and sodium sulphide it is boiled. The solution dissolves the chip in it to form a pulp. The pulp is next put through a pounding and squeezing process called beating. In order to finally turn the pulp into paper, the pulp is fed or pumped into giant, automated machines. One common type is called the

Fourdrinier machine. The paper then passes over a series of steam-heated cylinders to remove the remaining water. A large machine may have from 40 to 70 drying cylinders. The end product is thus the paper which we use in our daily life. See in figure 4.1.

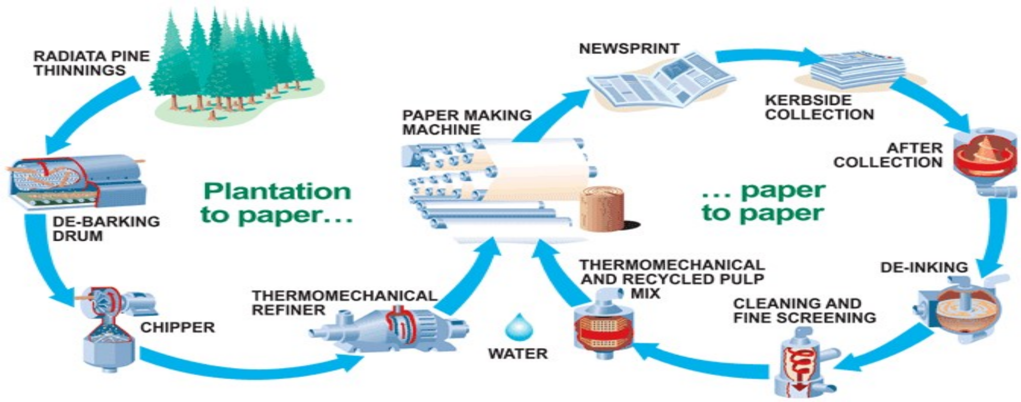

Figure 4.1: The process of making of paper.

4.3 Fabrication of CFI Pad

4.3.1 Collection of Material

As, the raw material in the fabrication of the cellulose tile is paper waste. Which is available in huge quantity. Now, the paper waste must be shredded in to small bites to easily make the paste. For this the use of shredder is idle. Figure 4.2.

Figure: 4.2 Shredded office paper

4.3.2 Soaking and Mixing of the Shredded Paper

Now, the shredded paper is mixed with the water to make a paste like consistency. This will help in easy moulding of the paste. The paste consist only of cellulose fiber after the de-inking process. The paste thus also refined by the use of industrial mixer to further break into more fine mesh. This would help in increasing the bounding between the fibers of the mesh, thus reduce the pores in number as well as size. See figure 4.3. The fine paste is thus could be used for making in any shape size of the insulation. It could also be used in the curved corners, ceiling, or any other abject. The flexibility provided by the paste gives the freedom to use it in n number of application.

Figure: 4.3 Shredded paper soaking

After the making of the paste, it is settled into square moulds and then it is compressed to bring out the excess water and also to reduce the thickness and increase the density and then it is left for drying. The drying process of different type. There could be a natural way like the open drying or sun-drying and there could be an artificial way like oven drying. After the dying process the square tile can be used directly over the wall, ceiling or to cover any internal part of the building. This tile will provide no air gap a tight seamless insulation.

4.3.3 Pressing and Drying of the CFI

While this process could also be repeated in the industrial scale with the help of large press and furnace. The paper paste could be laid down on the press, and the appropriate press applied to it will release excess water from the paste. Then, the semi dry pad could be transferred to the heated room to pre dry it. Before, drying in direct sunlight. It is necessary to dry it without trying to bake the paste. The purpose is to release all the moisture from the pad. The moisture left it could become the cause of the mold formation in it.

Figure: 4.4 Paper dough

There could also be reinforcement used inside the tile to provide strength and steadiness to the tie. This reinforcement could be of different type but the preferred one could be a net structure which hold the fiber to each other give it a rigid structure. The tile/pad could be used in the wall with the help of the glue or both side tape. The fitted pad will perform its function of insulating the room just as the traditional insulation thus.

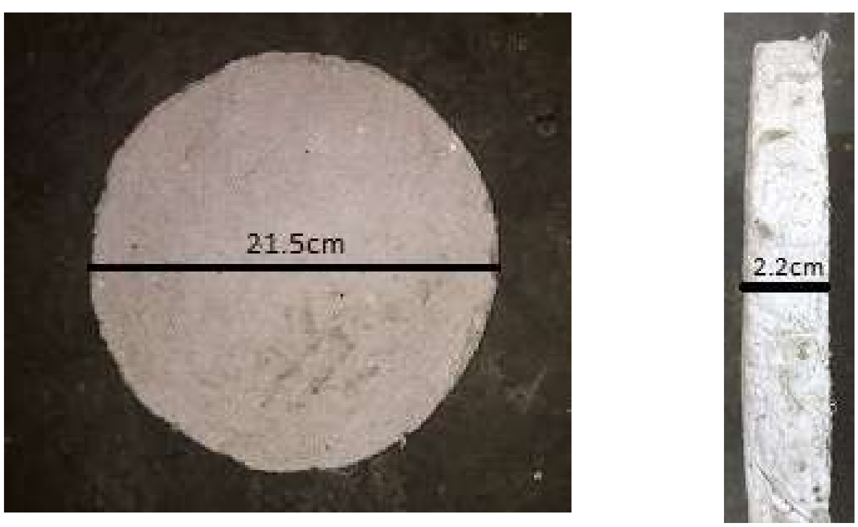

Figure: 4.5 CFI pad cross-section

This form of tile could easily applies over the wall. It has optimum thickness it could easily shaped by tool. Thus, it gives the flexibility. Once these tiles are dried up they are ready to be installed without spending more time this gives them edge over the method like wet spray method and loose fill method. The tiles are also easy to carry due to their light weight and could be transported to area where drying is difficult. It could be easily installed to the wall with the help of sticking agent which provides a tight seal between the surrounding.

4.4 Summary of the Chapter

The method used to fabricate the CFI pad is illustrated in the simple manner. There other methods of using CFI for the insulation. But, this pad provides the ease of applying this insulation. The fabrication process could easily be turned into industrial scale with high grade machines. In this chapter we have learned about the manufacturing of the insulation pad with the Cellulose Fibre as the raw material.

CHAPTER 5
RESULTS AND DISCUSSION

5.1 Introduction

In the previous chapters, we have seen the necessity to use the environmental friendly material, the comparison of the various insulation material, the property of CFI, the calculation to know the requirements and financial needs. In this last chapter, we have seen to fabricate the CFI pad

In this chapter, the numerical investigation of the Cellulose Fiber Insulation Pad is discussed in detail. The result of the final product has been shown with the help of the graph and table. The weather analysis of the city (Delhi, India) has been taken, to run the heat requirement analysis. The cost analysis is done to analyse the economic effect of the said material. The simulation of the present work is done on the software ANSYS FLUENT 18.2 to replicate the heat resistance of the material. The model is prepared on the 3D modelling software SOLIDWORKS 2018. In this chapter the table and graph are used to represent the cost comparison with the traditional material which is taken as EPS. The calculation is done to calculate the appropriate thickness of the Cellulose Fiber Insulation.

5.2 Cooling Loads and Heating Loads

The data is recorded 15th of every month for given period of the year for the taken insulation thickness. The 15th day is considered for the heat load. To figure every day absolute load, this immediate load is incorporated more than 24 hours periods. The 15th of every month is taken to observe the highest and lowest temperature for summer and winter conditions in Delhi, India., India. Along these lines, the fifteenth day as an agent day for every long stretch of the year is accepted in the table 5.1.

5.2.1 The Weather Analysis

In the present table 5.1 the average temperature of Delhi, India is shown. The date is retrieved from the climate-data and is confirmed by ICAR. The graph shows the trend that is followed and the need of the using the insulation material.

No.	Month-19	Daily Average Temperature(in °C)
1	January-19	14.2
2	Febuary-19	16.9
3	March-19	22.7
4	April-19	28.6
5	May-19	33.5
6	June-19	34.3
7	July-19	31.1
8	August-19	29.8
9	September-19	29.2
10	October-19	25.8
11	November-19	20.1
12	December-19	15.6

Table: 5.1 Average Temperature Data

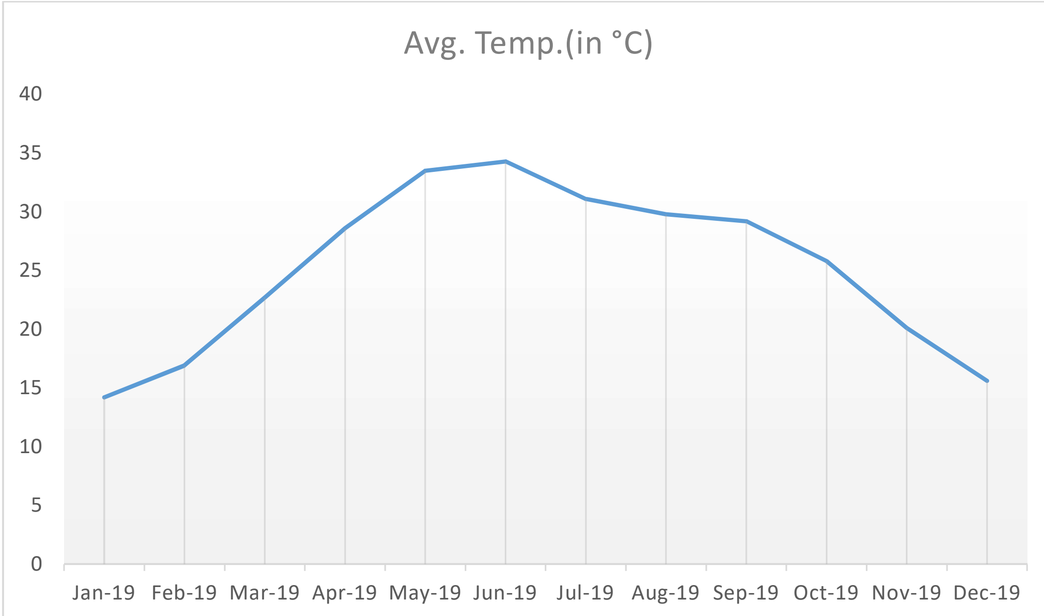

Figure: 5.1 Average Temperature of Delhi In 2019

The figure 5.1 shows the T_{avg} of the Delhi this data helps the further calculation for calculating the heat load of the building. In the above figure the need for cooling is from February to October where the average temperature is above the optimum temperature that is in this study taken as 21°C.

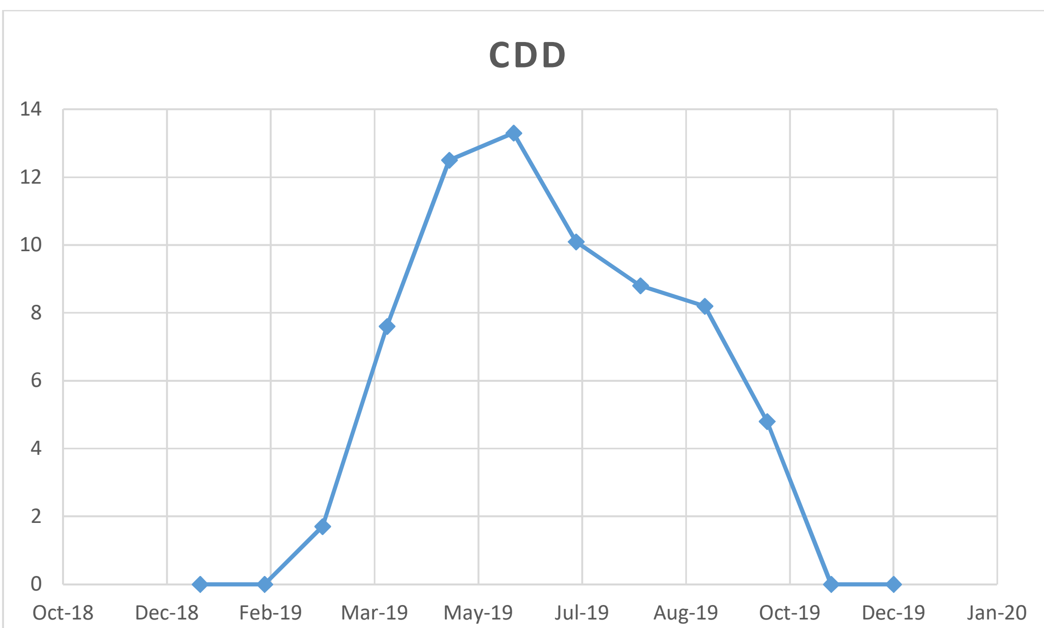

Figure: 5.2 Cooling Degree Day's Method of Delhi-2019

The degree day's method is one of the most dependable strategies for assessing the vitality utilization in structures. This strategy expect that the distinction in middle of surrounding temperature and the base temperature (T_b) is straightforwardly corresponding to the energy requirement of the structure. This method gives the value is used to calculate the heat load of the building. There are two method heating degree day method and cooling degree day method and they for heating and cooling requirement respectively.

In the figure 5.2 the graph is shown for cooling degree day method. In the graph the Tavg is subtracted from Tb and only positive value are taken negative values are taken as zero. This graph helps in calculating the cooling load for summers.

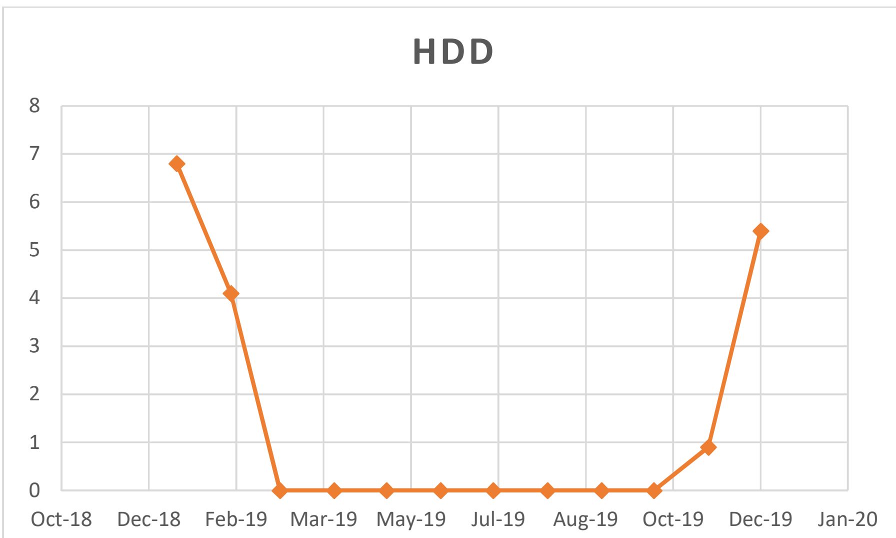

Figure: 5.3 Heating Degree Day's Method of Delhi-2019

In the figure 5.3 the figure is shown for heating degree day method. In the figure the Tb is subtracted from Tavg and only positive value are taken negative values are taken as zero. This graph helps in calculating the heating load for summers.

5.2.2 Heating and Cooling Load

At the reference day of each month, daily total cooling and heating transmission loads is taken. It is obvious that January and February give the highest heating loads, while July gives the highest cooling load. As expected under the climatic conditions of Delhi, the yearly heating transmission load is much lower than that for cooling. The overall heat transfer coefficient for the wall is 2.01 W/m^{2}k. So, by the equation 3.3 the yearly cooling and heating transmission loads is in the table 5.2 according to increasing insulation thickness for different insulation materials changes which will further be calculated. With the increase in the thickness of insulation transmission load decline. Be that as it may, this decrement is much quick for littler estimations of the thermal insulated thickness. Running loads for the building is taken for the wall made of bricks.

Month	Avg. Temp. in K	CDD in K	Cooling Load in W/m^2
Jan-19	14.2	0	0
Feb-19	16.9	0	0
Mar-19	22.7	1.7	317.4495
Apr-19	28.6	7.6	1419.186
May-19	33.5	12.5	2334.1875
Jun-19	34.3	13.3	2483.5755
Jul-19	31.1	10.1	1886.0235
Aug-19	29.8	8.8	1643.268
Sep-19	29.2	8.2	1531.227
Oct-19	25.8	4.8	896.328
Nov-19	20.1	0	0
Dec-19	15.6	0	0

Table: 5.2 Cooling Load for Delhi for 100 ft^2 Area

Month	Avg. Temp. in K	HDD in K	Heating Load in W/m^2
Jan-19	14.2	6.8	1269.798
Feb-19	16.9	4.1	765.6135
Mar-19	22.7	0	0
Apr-19	28.6	0	0
May-19	33.5	0	0
Jun-19	34.3	0	0
Jul-19	31.1	0	0
Aug-19	29.8	0	0
Sep-19	29.2	0	0

Oct-19	25.8	0	0
Nov-19	20.1	0.9	168.0615
Dec-19	15.6	5.4	1008.369

Table: 5.3 Heating Load of Delhi for 100 ft^2 Area

The above table gives the value for the heating and cooling load for various month of the year for Delhi, India. This data is further used to calculate the cost function of the used insulation and the economic status of the insulation. The above values are based on the empty 100m^2 Area room which is made of bricks of thermal conductivity of k is 0.87 W/mK.

5.3 Cost Analysis of the Insulation

The variation in energy vary with several factors, the most important of them is the management of the heat that has been gained or loss from either heating equipment or cooling equipment. This management saves lots of fuel in any form and apparently pays for itself in long term. Not only it saves the money that would be put as the cost of fuel but it also lowers the pollution of environment. Utilization of insulation in structures spares that additional expense. As the protection thickness applied to the wall expands, the absolute thermal resistance (R_t) increments and the heat loss from the wall diminishes. With the decrease of heat loss, the yearly fuel cost (C_H) diminishes. Be that as it may, the insulation cost ($C_{t,ins}$) increments as the insulation thickness increases. Thinking about these two costs, the absolute expense (C_{total}) diminishes first and afterward increases relying upon the expanded insulation thickness. The purpose behind this circumstance is that energy cost loses its adequacy in all out expense. The thickness for insulation where the total cost is minimum is taken as the optimum insulation thickness.

In the figure 5.4 the analysis of the cooling cost is presented according to the requirement of the month. The cost is calculate with the help of equation 3.5. Here, degree day method is used to calculate the need of energy CDD, the energy cost or electricity cost is taken according to the Delhi electricity bill i.e. Rs 7 per unit of electricity. An average usage of cooling device is considered to cool the room of 100 ft^2.

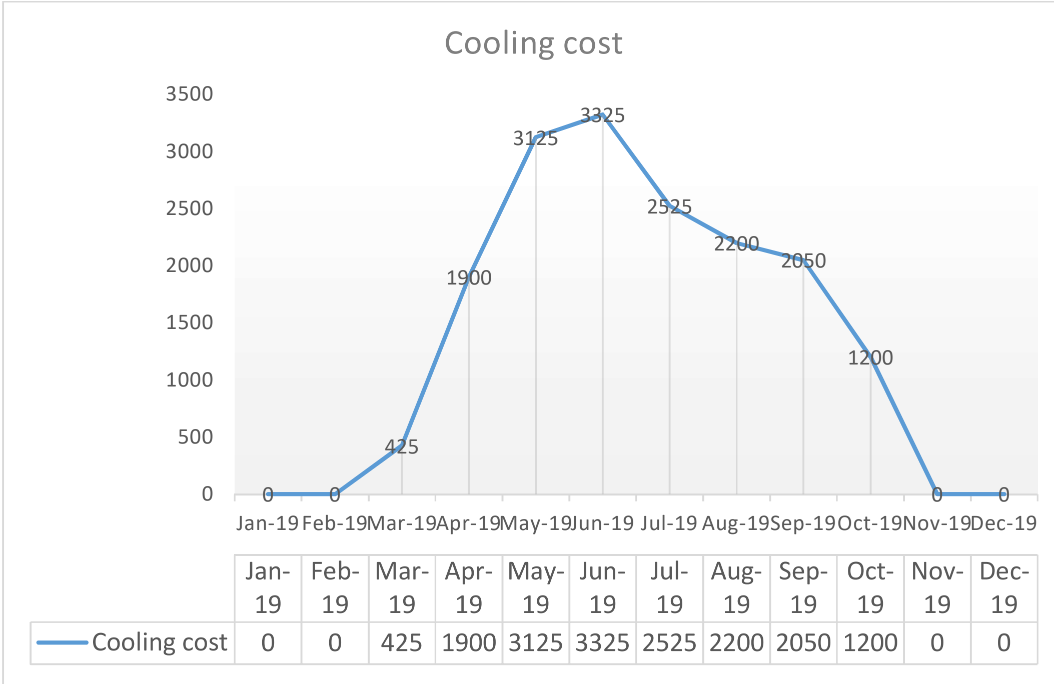

Figure: 5.4 Cooling Cost for 100 ft^2 Room in Delhi

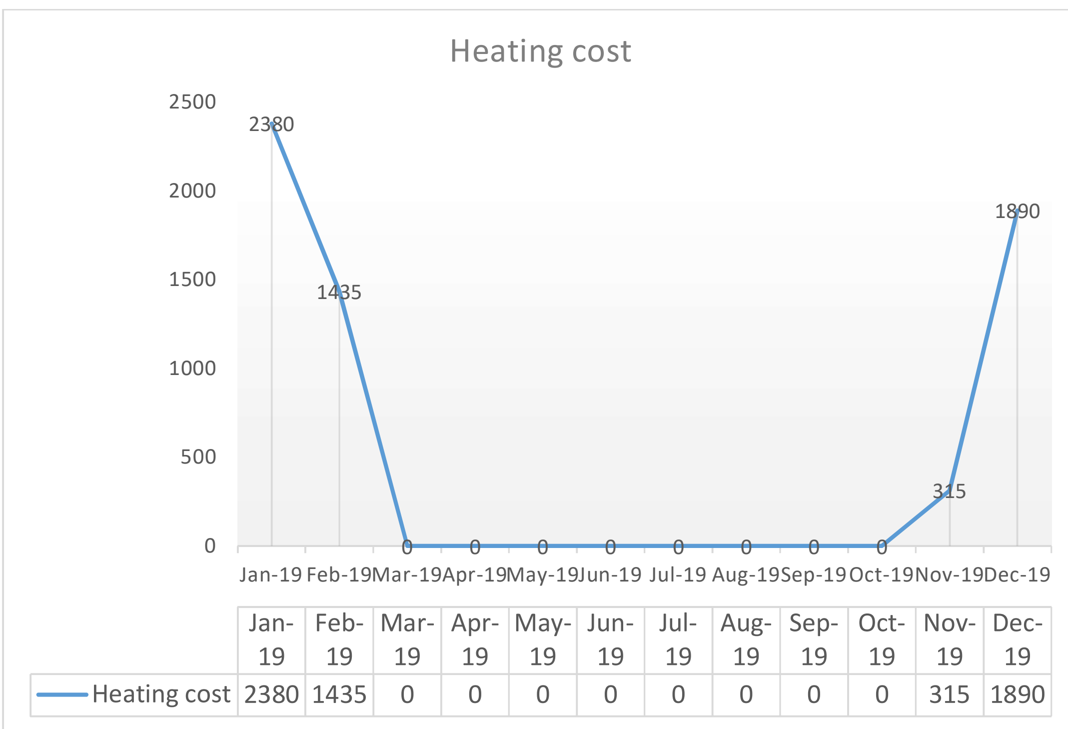

Figure: 5.5 Heating Cost for 100 ft^2 room in Delhi

Similarly, in the figure 5.5 the analysis of the heating cost is presented according to the requirement of the month. The cost is calculate with the help of equation 3.5. Here, degree day method is used to calculate the need of energy HDD, the energy cost or electricity cost is taken according to the Delhi electricity bill i.e. Rs 7 per unit of electricity. An average usage of cooling device is considered to cool the room of 100 ft2. The cost of insulation varies with the many factors location, thickness, material, etc. Here, EPS or expanded polystyrene is taken for comparison. For calculating the total cost C_{total} the market price of EPS is taken in Delhi. The room of 400 ft^2 surface area is taken as test subject. The cost of installation C_{int} is taken from market price of Delhi. The material price is taken from the website indiamart.com which come as 250Rs per square feet for the sheet of 5mm thickness C_{ins}. x is taken as variable thickness of the insulation

$$C_{total} = C_{int} + C_{ins} \times 400 \times x \qquad \text{..........(5.1)}$$

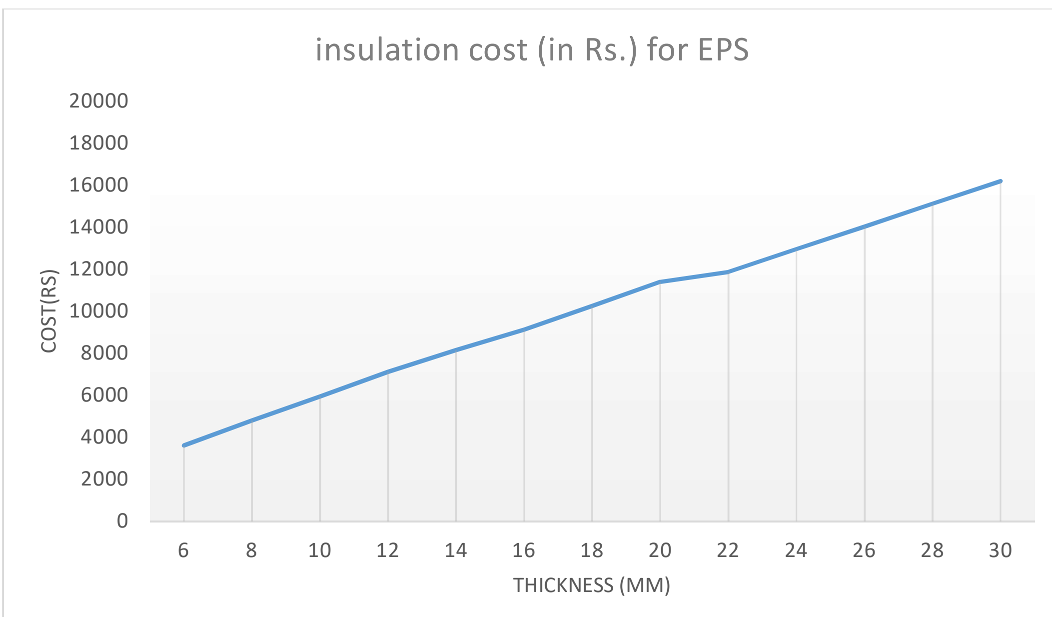

Figure: 5.6 Cost Of Insulation for Varying Thickness for EPS

Similarly, Here CFI or Cellulose Fiber Insulation is taken. For calculating the total cost C_{total} the market price of CFI. The room of 400 ft^2 surface area is taken as test subject. The cost of installation C_{int} is taken from market price of Delhi. The material price is taken from the market which come as 10Rs per Kg. which when factored with the cost of fabricating comes out to be 10Rs for square feet for the sheet of 5mm thickness C_{ins}. x is taken as variable thickness of the insulation

The similar equation 5.1 is used.

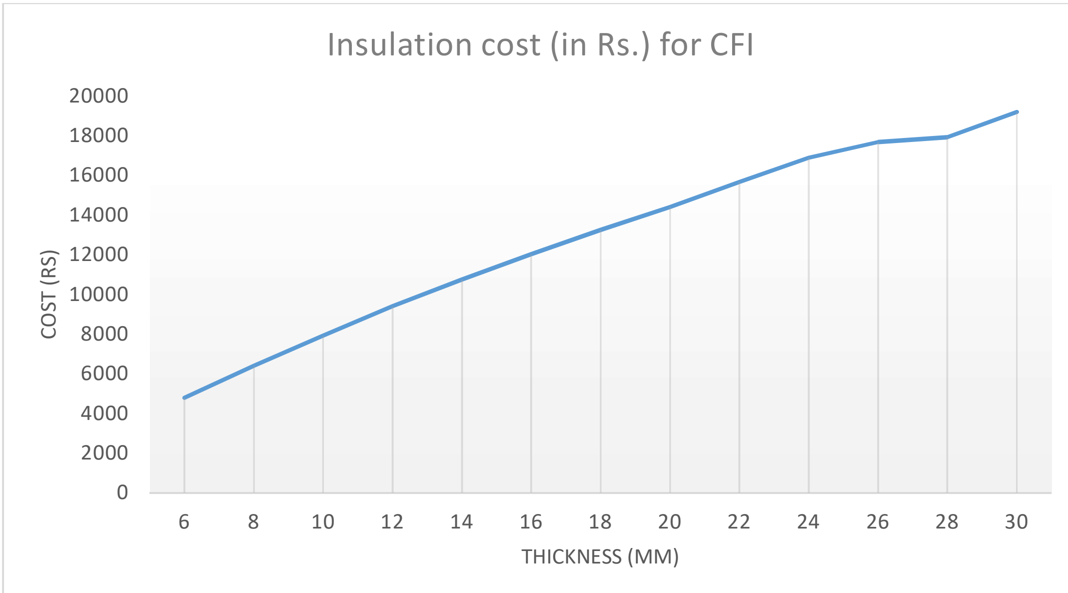

Figure: 5.7 Cost Of Insulation for Varying Thickness for CFI

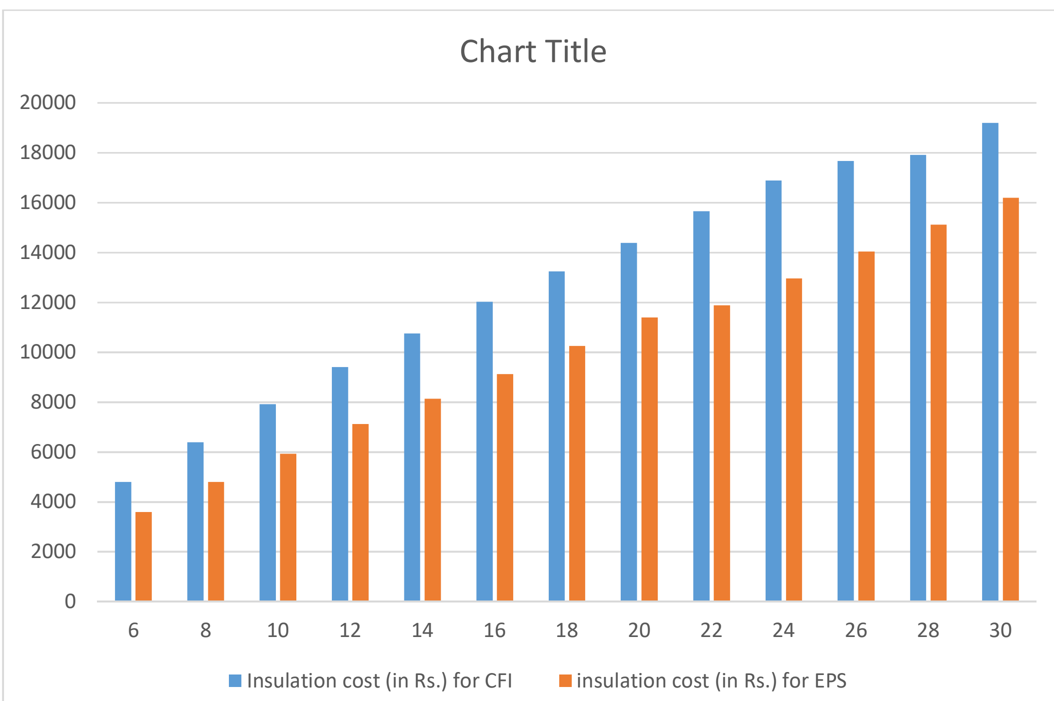

Figure: 5.8 Cost Comparison between CFI and EPS for Varying Thickness of Insulation

In figure 5.8, the comparison is shown between the two cost of the material and there installation. It can be seen that the cost of EPS insulation is lower than the CFI insulation. But, in this case we have to factor in that the cost of CFI is taken not from industrial scale, which can lower the significant amount.

As, EPS and XPS are mass produced material which make them cheaper in the market. The purpose of the study is to have an environment friendly recyclable material. Which CFI clearly outweigh its counterparts.

5.4 Analysis of Simulation Model of CFI

Cellulose Fiber Insulation or CFI is the insulation which is fabricated from the waste paper. The fabrication process is discussed in chapter 4 in detail. The waste paper is converted to paste and then applied to required area for insulation. The thermal conductivity of the 80gsm paper which is common office paper is 0.3-0.5 W/mK, the thermal conductivity for newspaper of 42 gsm or 1.02 g/cm^3 is 0.3-0.5 W/mK. The average cost for buying waste paper is cheap compared to other insulation resource material is 4 to 8 Rs/Kg from market survey report of India. The cost of CFI varies with the mass production which could give the economic edge as well environmental edge. Simulation model was prepared in SOLIDWORDKS 2018. The cylindrical model was prepared in which the inner cylinder of 100mm diameter and outer insulation layer of 5mm. The simulation was done on ANSYS FLUENT 18.2.in this the controlled inner cylinder environment was selected. The inner air was maintained at 340 K with side wall taken as insulated or no heat transfer. The inner connective heat transfer coefficient is taken as 2.5 W/m^{2}K. The outer convective heat transfer coefficient is taken as 25 W/m^{2}K [45]. 100 iterations were run to bring the result precise. The specific heat and density were taken for air are 1.00KJ/Kg and 1.225 Kg/m3 respectively and for insulation layer 1300 KJ/Kg and 1209 Kg/m^3 respectively. The dimension of the cylinder is 100mm in diameter and 500mm in depth. The reason of choosing this structure to get a uniform cross section for heat movement.

The result of simulation is shown in the figure 5.9 in this figure the cross section of cylinder is taken at 250 mm from both the end. The red area shows the constant heat to maintain the inner temperature at 340 K the outer temperature was taken at 300 K. After running the simulation for 5mm insulation layer the result is shown in figure 5.10.

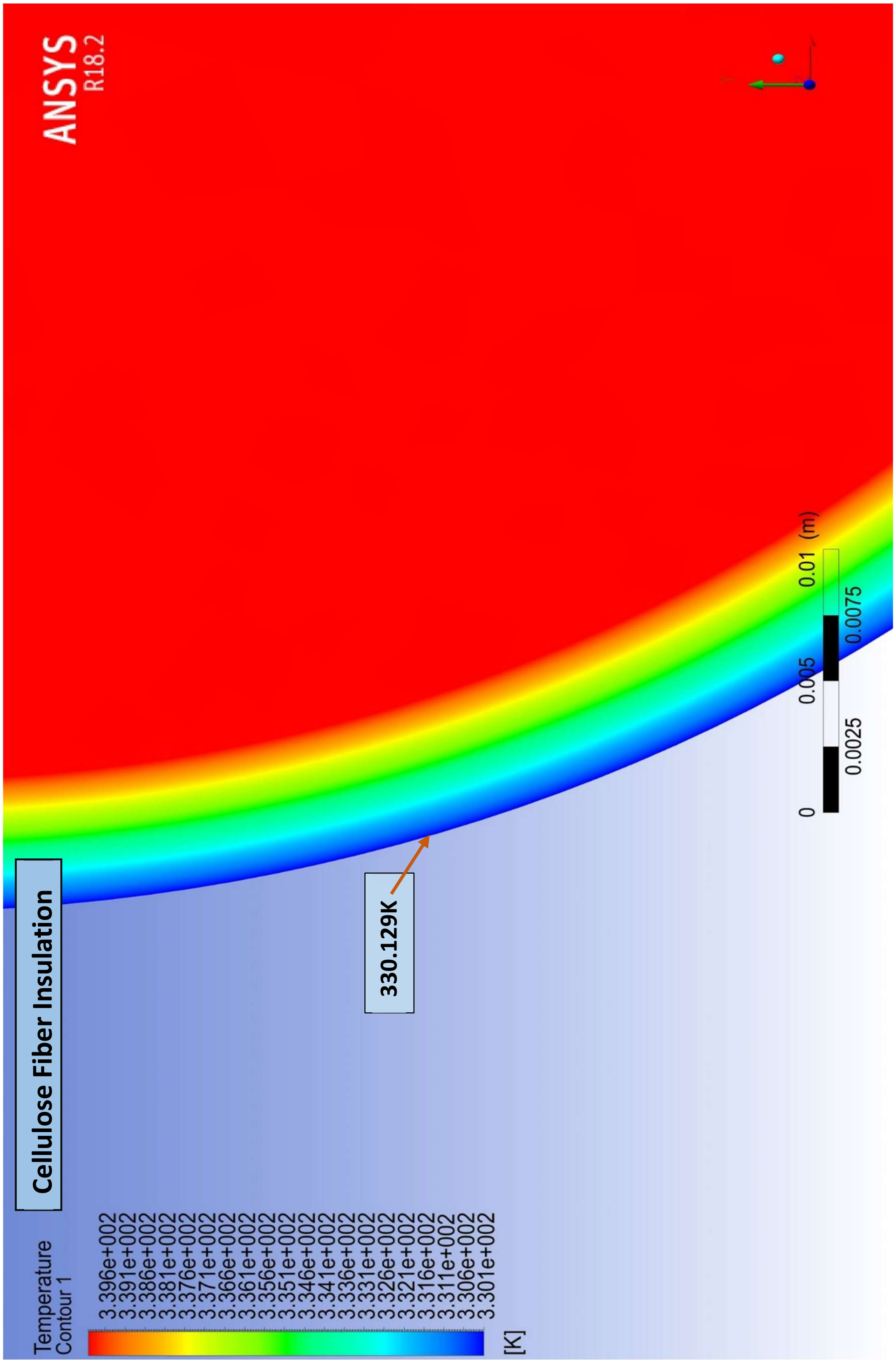

Figure: 5.9 Detailed Cross Section of Cylinder of CFI Showing Temperature Variance

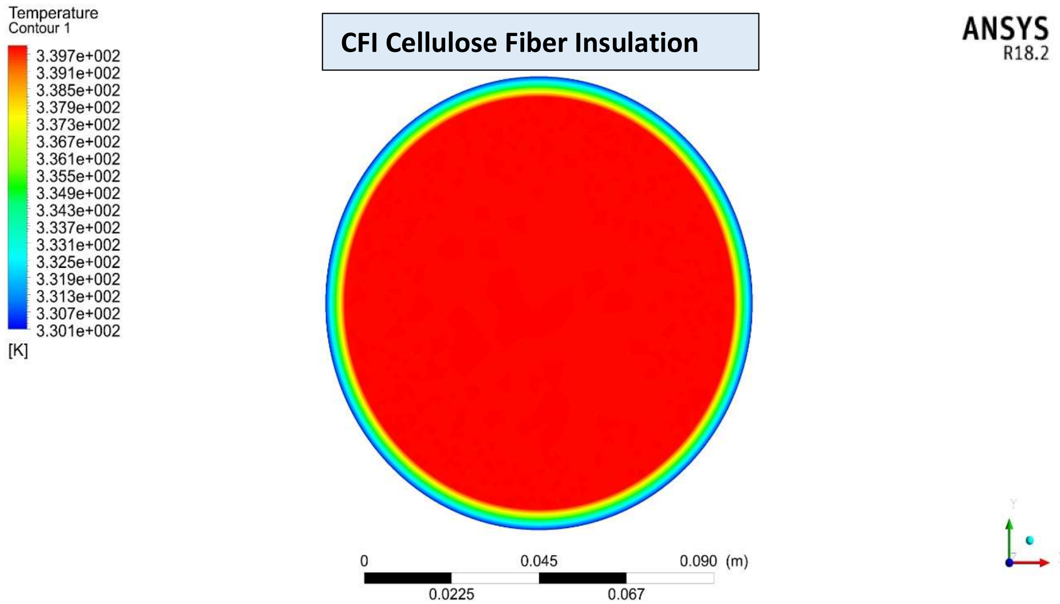

Figure: 5.10 Analysis of Cellulose Layer of Thickness 5mm

The figure 5.9, shows clearly that how effective the insulation layer. The outer layer temperature is at 330 K. The Heat flux of the air is 84.8586 W/m2 and Heat flux for insulation layer was 75.3226 W/m^2. The parameters for insulation thickness were varied to obtain the result of heat flux for different thickness. The range of thickness was taken from 0.25mm to 27.5mm. This range gives an approximation for the range of heat flux and decrease in the heat flux with increase in the insulation thickness.

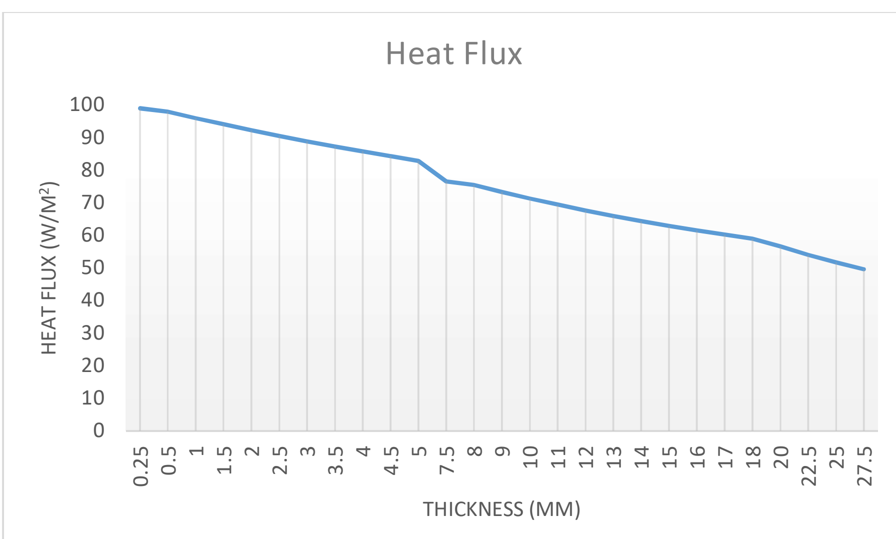

Figure: 5.11 Varying Insulation Thickness

In the figure 5.11 the graph shows the decrease of heat flux with increase in thickness. At CFI thickness of 27.5 mm the heat flux is 49.590591 W/m^2. This show that CFI insulation is efficient. For comparison the EPS insulation is taken. As the thickness go on increasing the heat flux decreases but with slower decrement with approximate 5% decrease in the following value difference.

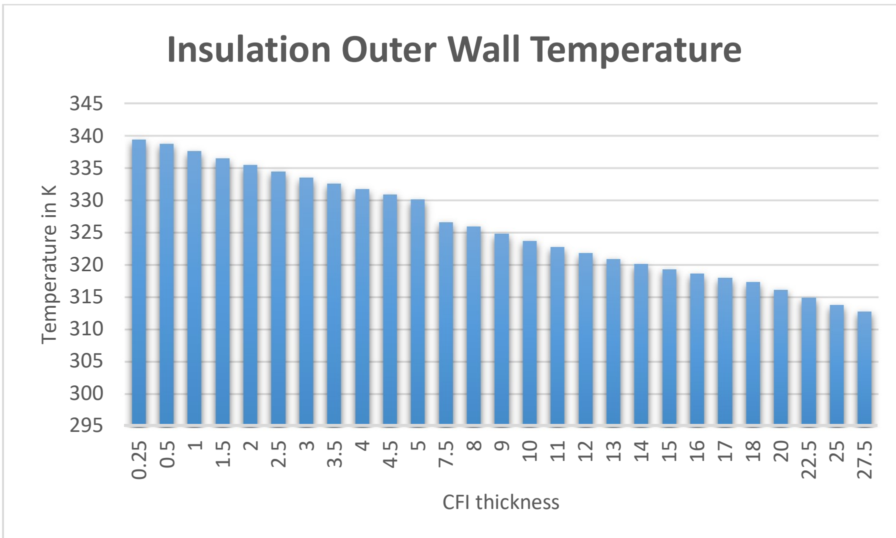

Figure: 5.12 Variation in Temperature with Thickness

Similarly, in the figure 5.12, the change in outer wall temperature with increase in temperature can be seen. The constant decrease in temperature shows the efficiency of the CFI insulation.

5.5 Comparative Analysis

For comparison with the other insulation material in this study EPS is considered. A similar was prepared separately for it. The values for density, specific heat capacity and thermal conductivity is taken as follows 20kg/m^3, 900KJ/Kg and 0.05 W/mK respectively. In this model the cross section of cylinder with 5mm insulation thickness can be seen in the figure 5.13 that the outer wall temperature is 339.748 K and the heat flux for the inner cylinder is 87.156 W/m^2. This result is with the 100 iteration in the simulation. The meshing was done to 300 divisions on to the outer wall and 20 for the surface. The simulation shows that there is difference which is clearly visible in the results. In the figure 5.13 the difference can be easily visible the changing of temperature through the insulation layer. Readings were recorded with change in the thickness similar to the CFI from 0.25mm to 27.5 mm there were 27 readings to compare.

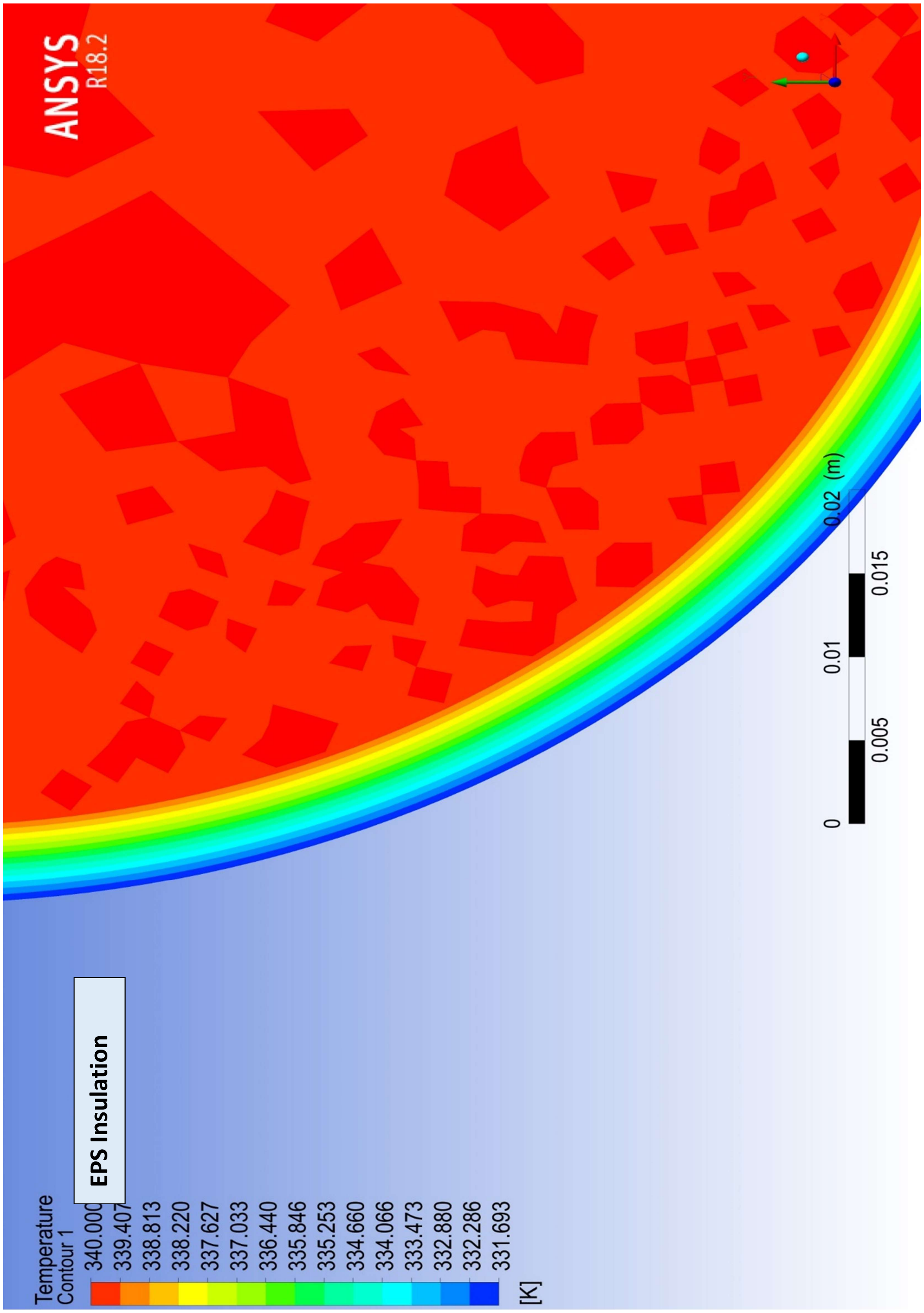

Figure 5.13 Detailed Cross Section of Cylinder of EPS Showing Temperature Variance

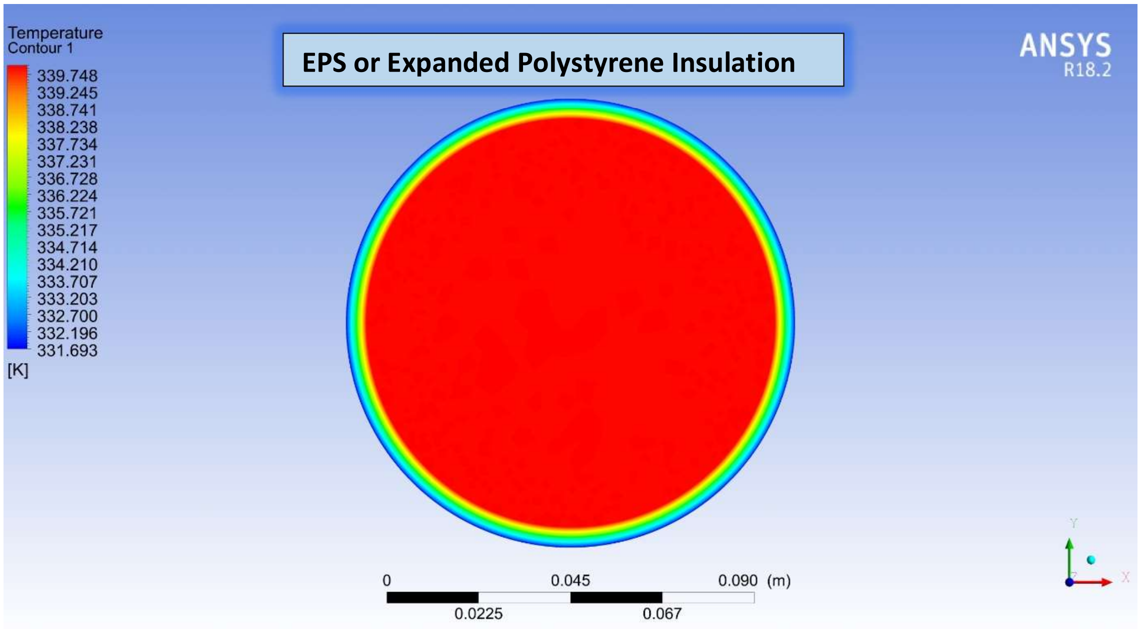

Figure: 5.14 Analysis of EPS insulation Layer of Thickness 5mm

5.4.1 EPS and CFI insulation comparison

In the table 5.4, the comparison shown between the CFI and EPS insulation. In this table the comparison is between the changing thickness and the heat flux. This compares the flow of heat through the insulation layer from the inner cylinder to the outer environment. The comparison shows that the CFI is more efficient from the EPS insulation from blocking the heat from escaping.

Insulation [mm]	CFI heat flux [W m^-2]	EPS heat flux [W m^-2]
0.25	98.950169	99.256299
0.5	97.924843	98.524802
1	95.944376	97.097287
1.5	94.052302	95.715276
2	92.242867	94.376712
2.5	90.510802	93.079658
5	82.854863	87.156452
7.5	76.549412	82.03515
10	71.266945	77.567079
15	62.914773	70.155371

20	56.608257	64.264108
22.5	54.000078	61.75087
25	51.675614	59.472396
27.5	49.590591	57.397324

Table: 5.4 Comparison between Heat Fluxes with Increasing Thickness

In the table 5.5, the comparison is shown between the thickness and outer wall temperature here, also it can be seen that CFI is performing better than the EPS. The reason is that the thermal conductivity of the CFI is less than the EPS which increases its efficiency then EPS.

Insulation [mm]	CFI insulation outer wall temp [K]	EPS insulation outer wall temp [K]
0.25	339.38315	339.50499
0.5	338.78212	339.01972
1	337.62525	338.07737
1.5	336.52517	337.17098
2	335.47803	336.29874
2.5	334.48031	335.45892
5	330.12904	331.69326
7.5	326.62588	328.53397
10	323.75565	325.85569
15	319.35839	321.58627
20	316.17379	318.36117
22.5	314.89657	317.03472
25	313.78016	315.85931
27.5	312.79757	314.81221

Table: 5.4 Comparison between Temperatures with Increasing Thickness

In the figure 5.15 and 5.16, the comparison id drawn between all the properties with thickness is taken as the reference line for the comparison.

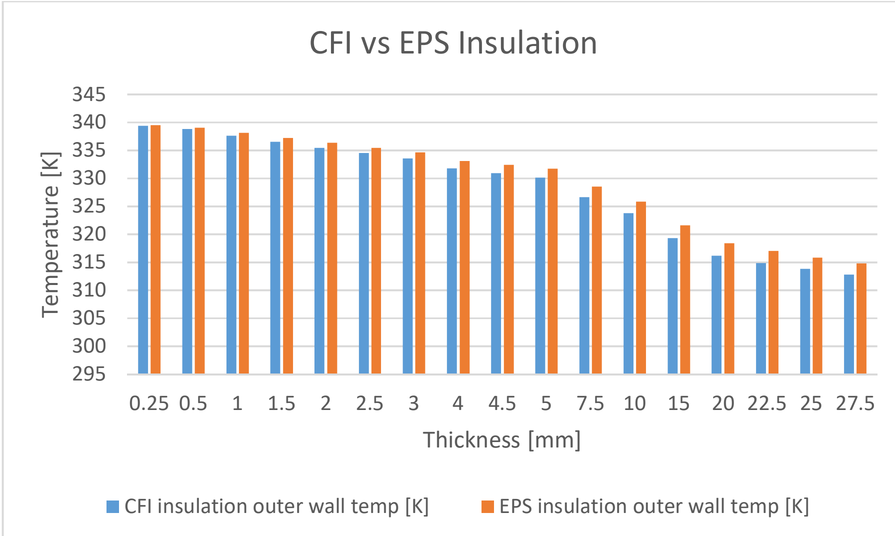

Figure: 5.15 Comparison between CFI vs EPS [Temperature]

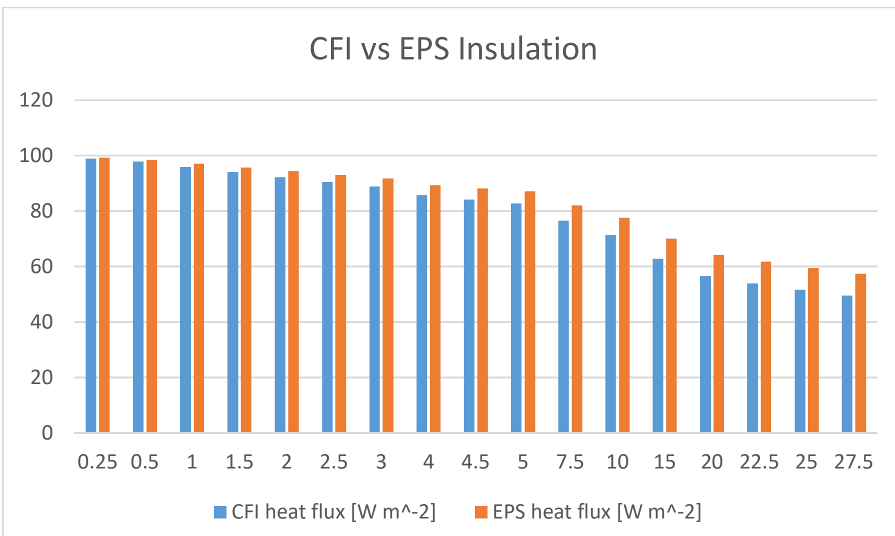

Figure: 5.16 Comparison between CFI vs EPS [Heat Flux]

The use of CFI in insulation has shown significant result when compared with the EPS insulation material with similar parameters in the account. The condition which were artificially generated may not correspond similarly with the practical conditions. But, the simulation is to give a virtual view that the performance of the CFI has effect over the traditional insulation.

5.5 Summary of the Chapter

This chapter has thoroughly discussed the analysis of the Cellulose Fiber Insulation Pad that has been discussed in the previous chapter. The simulation worked shown has been implemented with due time and parameters. The outcome has been stated as clearly as could be. Different parameters has been tried and changed to provide accurate idea of the presented work. All calculation done are based on the equation and summaries from previous chapters. The major finding of the results will be discussed and presented in the next chapter.

CHAPTER 6
CONCLUSION AND FUTURE WORK

This dissertation work has been done to obtain the usability of the Cellulose Fiber Insulation. Various parameters are implemented using ANSYS Fluent 18.2. SolidWorks based model was developed and simulated using ANSYS Fluent. The results were compared with similar model using different material. The parameters were kept similar in the condition. The cost analysis was done on the fabricated model and compared with the other material available in the market. The following conclusions were drawn from this work.

6.1 Conclusions

- The fabrication of the CFI pad was done on small scale with few material. The large scale production of the CFI Pad is possible and would lower the overall cost of the insulation.
- The dynamic modelling of the Cellulose Fiber Insulation has been performed computationally using ANSYS Fluent.
- The simulation done on the CFI has shown that the insulation was performing its purpose fully and showing good resistance from the heat.
- The cost analysis has shown that using the CFI insulation has similar cost as compared to other insulation. But, with the mass production of the insulation could do better.
- The cost analysis of the CFI has shown that installing the insulation has significant impact on the saving of energy and that it would eventually recover it cost in 2-3 years.
- The comparison between the thermal properties of the CFI and EPS Insulation has been done. The result has shown difference between them with CFI being more efficient.

- The use of paper waste in the manufacturing process lowers the carbon footprint of the building and recycles the paper waste.

6.2 Future Work

- CFI Pad has lots of potential in the insulation market, and would compete with the existing insulation technologies easily.
- CFI Pad could be further improved by adding fire resistance and waterproofing element to make it more desirable and efficient.
- Economic and Environmental benefits of the CFI could be further explored and be turned into more useful material any other technologies, evidently replacing the non-eco-friendly material.
- The Pad could be also used as temporary home by increasing their strength and durability which could also help in poor countries and the poor people to have efficient shelter.

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APPENDIX A
DEFINITIONS

Heat energy

One kilocalorie (1 kcal or 1 000 calories) is the amount of heat (energy) needed to raise the temperature of one kg of water by one degree Celsius (°C). The SI standard unit for energy is Joule (J). One kcal is approximately 4.18 kJ (this varies slightly with temperature). Another unit is the Btu (British thermal unit). One Btu corresponds roughly to 1 kJ.

Thermal conductivity

In simple terms this is a measure of the capacity of a material to conduct heat through its mass. Different insulating materials and other types of material have specific thermal conductivity values that can be used to measure their insulating effectiveness. It can be defined as the amount of heat/energy (expressed in kcal, Btu or J) that can be conducted in unit time through unit area of unit thickness of material, when there is a unit temperature difference. Thermal conductivity can be expressed in kcal m-1 °C-1, Btu ft-1 °F-1 and in the SI system in watt (W) m-1 °C-1. Thermal conductivity is also known as the k-value.

Coefficient of thermal conductance " l" (kcal m-2 h-1 °C-1)

This is designated as l (the Greek letter lambda) and defined as the amount of heat (in kcal) conducted in one hour through 1 m2 of material, with a thickness of 1 m, when the temperature drop through the material under conditions of steady heat flow is 1 °C. The thermal conductance is established by tests and is the basic rating for any material. l can also be expressed in Btu ft-2 h-1 °F-1 (British thermal unit per square foot, hour, and degree Fahrenheit) or in SI units in W m-2 Kelvin (K)-1.

Thermal resistivity

The thermal resistivity is the reciprocal of the k-value (1/k).

Thermal resistance (R-value)

The thermal resistance (R-value) is the reciprocal of l (1/l) and is used for calculating the thermal resistance of any material or composite material. The R-value can be defined in simple terms as the resistance that any specific material offers to the heat flow. A good insulation material will have a high R-value. For thicknesses other than 1 m, the R-value increases in direct proportion to the increase in thickness of the insulation material. This is x/l, where x stands for the thickness of the material in metres.

Coefficient of heat transmission (U) (kcal m-2 h-1 °C-1)

The symbol U designates the overall coefficient of heat transmission for any section of a material or a composite of materials. The SI units for U are kcal per square metre of section per hour per degree Celsius, the difference between inside air temperature and outside air temperature. It can also be expressed in other unit systems. The U coefficient includes the thermal resistances of both surfaces of walls or flooring, as well as the thermal resistance of individual layers and air spaces that may be contained within the wall or flooring itself.

Permeance to water vapour (pv)

This is defined as the quantity of water vapour that passes through the unit of area of a material of unit thickness, when the difference of water pressure between both faces of the material is the unit. It can be expressed as g cm mmHg-1 m-2 day-1 or in the SI system as g m MN-1 s-1 (grams metre per mega Newton per second).

Resistance to water vapour (rv)

This is the reciprocal of the permeance to water vapour and is defined as rv = 1/pv.

APPENDIX B
BUILDING ELEMENTS - HEAT LOSS AND THERMAL RESISTIVITY

Thermal resistance in common building elements - like walls, floors and roofs above and below the ground

Thermal resistance in some common building elements are indicated in the table below. The values can be used to approximately heat loss calculations from buildings.

Thermal Resistance Inside and Outside Walls	**Resistance** ***(m²K/W)***		
	$R_i = 1/f_i$ [1)]	$R_o = 1/f_o$ [1)]	$R_i + R_o$
Building parts against the surrounding environment	0.13	0.04	0.17
Building parts others	0.13	0.13	0.26

Thermal Resistance for Building Elements against Earth	**Resistance** ***(m²K/W)***
	R_e
Floors 0.5 m above to 0.5 below earth bound, 0-1 m from inside outside wall - without cold bridge protection	0.2
Floors 0.5 m above to 0.5 below earth bound - with cold bridge protection	1.0
Center-field above 1 m from inside outside wall	1.5
Basement floors 0.5 m below earth bound	2.0
Basement walls under earth bound, the whole wall against the earth, where *h* is the basement floors level below the earth bound (m)	0.2 + 0.3 *h*
Basement walls under earth bound, basement floor against the earth and partly against air	2.0

- 1 *K/W = 0.5275 (h °F)/Btu*

APPENDIX C

HEAT LOSS FROM BUILDINGS

Overall heat transfer loss from buildings - transmission, ventilation and infiltration

The overall heat loss from a building can be calculated as

$H = H_t + H_v + H_i$ (1)

where

H = overall heat loss (W)

H_t *= heat loss due to transmission through walls, windows, doors, floors and more (W)*

H_v *= heat loss caused by ventilation (W)*

H_i *= heat loss caused by infiltration (W)*

1. Heat loss through walls, windows, doors, ceilings, floors, etc.>

The heat loss, or norm-heating load, through walls, windows, doors, ceilings, floors etc. can be calculated as

$H_t = A\ U\ (t_i - t_o)$ (2)

where

H_t *= transmission heat loss (W)*

A = area of exposed surface (m^2)

U = overall heat transmission coefficient (W/m^2K)

t_i *= inside air temperature* (^oC)

t_o*= outside air temperature* (^oC)

Heat loss through roofs should be added *15%* extra because of radiation to space. (2) can be modified to:

$H = 1.15\ A\ U\ (t_i - t_o)$ (2b)

For walls and floors against earth (2) should be modified with the earth temperature:

$H = A\ U\ (t_i - t_e)$ (2c)

where

t_e*= earth temperature* (^oC)

Overall Heat Transmission Coefficient

The overall of heat transmission coefficient - *U* - can be calculated as

$U = 1 / (1 / C_i + x_1 / k_1 + x_2 / k_2 + x_3 / k_3 + .. + 1 / C_o)$ (3)

where

C_i = surface conductance for inside wall (W/m²K)

x = thickness of material (m)

k = thermal conductivity of material (W/mK)

C_o= surface conductance for outside wall (W/m²K)

The conductance of a building element can be expressed as:

$C = k / x$ *(4)*

where

C = conductance, heat flow through unit area in unit time (W/m²K)

Thermal resistivity of a building element is the inverse of the conductance and can be expressed as:

$R = x / k = 1 / C$ *(5)*

where

R = thermal resistivity (m²K/W)

With (4) and (5), (3) can be modified to

$1 / U = R_i + R_1 + R_2 + R_3 + .. + R_o$ *(6)*

where

R_i = thermal resistivity surface inside wall (m²K/W)

$R_{1..}$ = thermal resistivity in the separate wall/construction layers (m²K/W)

R_o = thermal resistivity surface outside wall (m²K/W)

For walls and floors against earth (6) - can be modified to

$1 / U = R_i + R_1 + R_2 + R_3 + .. + R_o + R_e$ *(6b)*

where

R_e = thermal resistivity of earth (m²K/W)

2. Heat loss by ventilation

The heat loss due to ventilation without heat recovery can be expressed as:

$H_v = c_p \rho q_v (t_i - t_o)$ *(7)*

where

H_v = ventilation heat loss (W)

c_p = specific heat air *(J/kg K)*

ρ = density of air (kg/m³)

q_v = air volume flow (m³/s)

t_i = inside air temperature (°C)

t_o = outside air temperature (°C)

The heat loss due to ventilation with heat recovery can be expressed as:

$H_v = (1 - \beta/100)\ c_p\ \rho\ q_v\ (t_i - t_o)$ *(8)*

where

β = heat recovery efficiency (%)

An heat recovery efficiency of approximately 50% is common for a normal cross flow heat exchanger. For a rotating heat exchanger the efficiency may exceed *80%*.

3. Heat loss by infiltration

Due to leakages in the building construction, opening and closing of windows, etc. the air in the building shifts. As a rule of thumb the number of air shifts is often set to *0.5* per hour. The value is hard to predict and depend of several variables - wind speed, difference between outside and inside temperatures, the quality of the building construction etc.

The heat loss caused by infiltration can be calculated as

$H_i = c_p\ \rho\ n\ V\ (t_i - t_o)$ *(9)*

where

H_i = heat loss infiltration (W)

c_p = specific heat air (J/kg/K)

ρ = density of air (kg/m^3)

n = number of air shifts, how many times the air is replaced in the room per second (1/s) (0.5 1/hr = 1.4 10^{-4} 1/s as a rule of thumb)

V = volume of room (m^3)

t_i = inside air temperature (^{o}C)

t_o = outside air temperature (^{o}C)

APPENDIX D
PAPER WASTE

Facts about Paper and Paper Waste

- As we speak, more than 199 tons of paper has already been produced.
- 324 liters of water is used to make 1 kilogram of paper.
- 10 liters of water is needed to make one piece of A4 paper.
- 93% of paper comes from trees.
- 50% of the waste of businesses is composed of paper.
- To print a Sunday edition of the New York Times requires 75,000 trees!
- Recycling 1 ton of paper saves around 682.5 gallons of oil, 26,500 liters of water and 17 trees.
- Packaging makes up 1/3 or more of our trash.

- U.S offices use 12.1 trillion sheets of paper a year.
- Paper accounts for 25% of landfill waste and 33% of municipal waste.
- With all the paper we waste each year, we can build a 12 foot high wall of paper from New York to California!
- Lessening of paper usage was predicted due to the electronic revolution. It didn't happen. Demand for paper is expected to double before 2030.
- Every tree produces enough oxygen for 3 people to breathe.

Environmental Effects of Paper Waste

Deforestation is the primary effect of our mindless use of paper. Conservation groups have made an admirable headway in protecting ecologically rich forests and limiting commercial access. This is great progress for mankind! Just imagine how long a tree will grow to its full size…. We are only just realizing the wasted use of our trees - trees that give off oxygen and protect the planet from further Global Warming.

Paper pollution is another effect of paper waste and it's a serious problem. It is estimated that by 2020, paper mills will be producing 500,000,000 tons of paper and paperboard each year! We obviously need this product and a reduction of use is not in the horizon. Pulp and paper is the 3rd largest industrial polluter of air, water and soil. Chlorine-based bleaches are used during production which results in toxic materials being released into our water, air and soil. When paper rots, it emits methane gas which is 25 times more toxic than CO2.

10 Easy Ways to Reduce Paper Waste and Pollution

In North America, many paper companies are now modifying their processes to reduce the formation of dioxins. Dioxin is a toxic by-product of the manufacture of paper and it is a carcinogen. We are now seeking renewable sources of paper so we don't have to cut down our beautiful life-giving trees.

What can you do from your end to reduce paper pollution and waste?

1. Recycle all your paper waste.
2. Be a conscious consumer and buy "100% post-consumer waste recycled". Buy recycled paper materials or materials that came from sustainable managed forests.
3. In the office, reuse paper. If you've only used one side for example, collect them instead of throwing them away. You can bind these sheets and make a notebook using the other side. This small effort reduces paper waste by 50%
4. If you already have a scanned copy of a file, don't print it anymore unless really needed.
5. Use email instead of paper when communicating with clients and customers.
6. Reduce the use of paper cups and disposable paper plates by keeping reusable items in the office pantry.
7. Encourage your officemates and friends to recycle their paper by putting them in recycling bins.
8. Insist on "Process Chlorine Free" paper materials.
9. Buy products with the least paper packaging. Encourage businesses that follow environment friendly practices.

10. Take advantage of the latest technologies like tablets, computers and smart phones to keep your files and notes.

As a consumer, the way you use and dispose of paper and other paper products greatly affect our paper waste. These small efforts on your part will be a valuable contribution in the resolution of our pollution problems today.