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Insulation materials. Cellulose fiber and Expanded polystyrene Insulations.

STUDY OF INSULATION MATERIALS, PROPERTIES AND BEHAVIORS.

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0. <u>Introduction:</u>

In this final project, I choose this topic on one hand because architecture had been always important for me sice I was in the school and the teachers show me modern architecture and Gaudi's works, for me was a point in my life that change me to start doing what I'm studying and since that days I can appreciate the architecture.

On the other hand I think that it's an important part of the constructions that we can't see and we don't give them importance, but without them we don't have comfortable buildings and they make us a comfortable life.

The main role of thermal insulation materials in a building envelope are to prevent heat loss and provide thermal comfort for a building's interior.

The factor that characterizes an insulation material's effectiveness is its thermal conductivity λ (measured in W/mK). The lower a material's thermal conductivity, the more effective it is as an insulator.

Traditional insulation materials include glass fibre, stone wool, expanded polystyrene, and polyurethane foam. While these materials are efficient in maintaining thermal comfort to a buildings interior, they are made with non-renewable resources and have a high embodied energy.

Consequently, there is an increasing interest for alternative insulating materials that come from renewable or recycled fibres. Natural fibres such as jute, flax and hemp have shown to be suitable alternatives to mineral insulation and are the subject of numerous research projects.

One such material is cellulose fibre insulation (CFI). Comprising mostly of recycled paper fibres, cellulose is increasing in popularity due to its eco-friendly nature and favourable thermal and acoustic properties. Even amongst other insulation materials CFI presents some of the lowest embodied energy per kg of material.

Theorical part

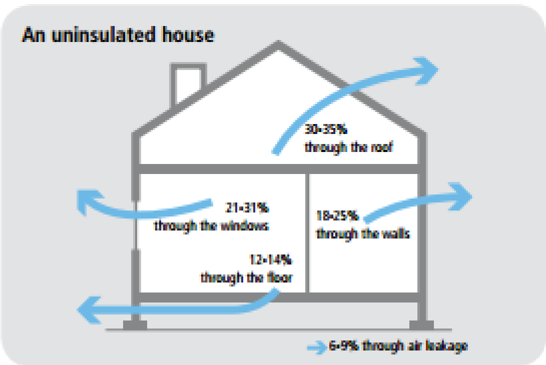
1. Thermal Insulations:

1.1 What's an Insulation?

Thermal insulation materials are an essential part of a building envelope. They assure that the inside temperature of a room is maintained at a certain level and reduce the use of heating and cooling, which have a high energy demand. [1]

Thermal insulation is undoubtedly one of the best ways to reduce the energy consumption due to both winter heating and summer cooling. Insulation materials play an important role in this area since the selection of the correct material, its thickness and its position, allow to obtain good indoor thermal comfort conditions and adequate energy savings. Thermal properties are extremely important, but they are not the only ones to be considered when designing a building envelope: sound insulation, resistance to fire, water vapor permeability and impact on the environment and on human health need to be carefully assessed too. [2] According to EN ISO 9229 thermal insulatin materials are materials with thermal conductivity lower then 0,1 $w.m^{-1}.K^{-1.}$

We need to know their properties to understand what we need and choose the correct insulation.



Pic.1. [39] An uninsulated house.

European Parliament and the Council its a Directive aims to promote the energy performance of buildings and building units. Controling [3]:

- Having regard to the Treaty on the Functioning of the European Union, and in particular Article 194(2) thereof.
- Having regard to the proposal from the European Commission.
- Having regard to the opinion of the European Economic and Social Committee.
- Having regard to the opinion of the Committee of the Regions.

- Acting in accordance with the ordinary legislative procedure.

1.2 Properties of insulation materials:

1. Thermal characterization:

The thermal insulation material has main parameters in thermal field, are the thermal conductivity [*λ*], measures the ease with which heat can travel through a material by conduction and the thermal diffusivity [*a*], measures the ability of a material to conduct thermal energy relative to its ability to store thermal energy.

Thermal conductivity is the heat flow that passes through a unit area of a 1 m thick homogeneous material due to a temperature gradient equal to 1 K; it is expressed in W/m K. The unsteady or dynamic conditions are to be considered when the heat flow rate or the temperature varies on one or both of the boundaries of the considered component.

The thermal diffusivity is the ratio between thermal conductivity, i.e. the ability to conduct thermal energy, and the product of density [*ρ*] and specific heat [*Cp*], which express the ability of the material to store thermal energy: so thermal diffusivity describes the propagation of thermal waves inside the media. It is expressed in m^2/s and it is a derived quantity composed by intrinsic properties of the material.

For a multi-layer wall, thermal properties are expressed by thermal transmittance, [*U*], which is the heat flow that passes through a unit area of a complex component or inhomogeneous material due to a temperature gradient equal to 1 K; it is expressed in W/m^2 K.

The inverse of thermal transmittance is the thermal resistance, or [*R-value]*. Thermal transmittance considers also the thickness of an insulator and the heat transfer due to convection and radiation.[6]

Table 5-1 Comparison of Insulation Materials (Environmental Characteristics, Health Impacts)			
Type of Insulation	**Installation Method(s)**	**R-value per inch**	**Indoor Air Quality Impacts**
		Fiber Insulation	
Cellulose	Loose-fill, wet-spray dense pack, stabilized	3.0 – 3.7	Fibers and chemicals can be irritants, should be isolated from interior space
Fiberglass	Batts, loose- fill, stabilized, rigid board	2.2 – 4.0	Fibers and chemicals can be irritants, should be isolated from interior space
Mineral Wool	Loose-fill, batts	2.8 – 3.7	See fiberglass
		Foam Insulation	
Open-cell Expanded Polystyrene (beadboard)	Rigid boards	3.6 – 4.2	Concern only for those with chemical sensitivities
Closed-cell Extruded Polystyrene	Rigid boards	5	Concern only for those with chemical sensitivities
Closed-cell Polyisocyanurate	Foil-faced rigid boards	5.6 – 7.7	Concern only for those with chemical sensitivities
Closed-cell Phenolic Foam	Foil-faced rigid board	8	Concern only for those with chemical sensitivities
Open-cell Polyicynene	Sprayed-in	3.6	
Open-cell Soy-based Foam	Sprayed-in	3.6	
Closed-cell Polyurethane	Sprayed-in	5.6 – 6.8	Concern only for those with chemical sensitivities
Open-cell Polyurethane	Sprayed-in	4.3	Unknown, appears to be very safe

Pic.2. Chapter 5 Insulation Materials and Techniques. University of Kentucky.

An [*R-value*] is a measure of the thermal resistance of a material. Higher [*R-values*] indicate better resistance to heat flow through material.

2. Acoustic characterization:

From an acoustic point of view, in order to absorb sound, materials should have high porosity to allow the sound to enter in their matrix, and for dissipation. Pores isolated from other adjacent pores, also called “closed” pores, allow some level of sound absorption, but only “open” pores, which guar-antee a continuous channel of communication with the external surface of the material, allow higher sound absorption properties.[5]

In the first case airborne and structural (impact) sound insulation properties are considered. Sound absorption, on the other hand, defines the part of the acoustic energy dissipated inside a material because of friction or thermal loss (porous materials). While porous sound absorbers are usually good thermal insulators, the vice versa is not always true: sound absorbers requires the presence of air moving inside the material, so open porosity is essential; on the contrary closed porosity is usually beneficial for thermal insulators because of the presence of still air inside the cavities.

As far as airborne sound insulation, this characteristic is strongly dependent on the mass of the materials: lightweight materials are commonly poor sound insulators. The sound insulation of a massive structure depends mainly on the performance of the heaviest components, such as masonry or concrete.

If a double wall is concerned, the presence of a sound absorbing material in the gap allows to limit cavity resonances and consequently to increase the sound insulation of the wall. Sound absorbers are used to reduce the reverberation time of rooms, with a beneficial effect on acoustic comfort and on speech comprehension. Optimal values of reverberation time are defined according to the activities to be performed inside the room and to its volume. If sound insulation of floors is concerned, impact sound insulation must be considered, i.e. the ability to contrast the transmission of impact sounds (footsteps, falling objects, etc.) through the floor structure. In this case the solutions to achieve good performance are the following: 1. Install a false ceiling in the disturbed lower room, 2. Lay a resilient layer on the pavement of the disturbing upper room, such as vinyl or carpet, or 3. Create a floating floor in the upper room, i.e. a floor separated by the structural slab by means of a resilient layer. The most important parameter to consider for selecting an effective resilient layer is dynamic stiffness [*s'*], which should be comprised between 4 (best value) and 50 MN/m^3, according to Standard EN ISO 29052-1 [MN/m^3]. [4]

Acoustic insulation can be assessed for airborne and impact sound for real-sized or small samples; in the first case measurements can be performed in laboratory or in situ. Concerning impact sound insulation, an estimation of the sound insulation performance of a floating floor can be made using the results of dynamic stiffness measurements performed on small sized samples (0.04 m^2). Sound absorption of materials can be measured in a number of ways; most commonly it is measured in diffuse sound field inside a reverberation room, ISO 10140 or in an impedance tube in a plane wave field, ISO 10534. [6]

3. Environmental characterization: Life Cycle Assessment:

Life Cycle Assessment (LCA) is a well-defined methodology to assess the environmental impact of services or products. The procedures to perform this evaluation are specified in the ISO standards 14040 and 14044. LCA allows to measure the environmental burden through several indicators; the most used ones are the Cumulative Energy Demand (CED) and the Global Warming Potential (IPPC GWP 2007).

CED is the primary energy consumed directly and indirectly during the considered life cycle of the assessed product. IPPC GWP 2007 is used to

evaluate the impact to the global warming of a product during its life cycle; it takes into account all the gas emissions, which are calculated in terms of kilograms of CO_2 equivalent. The indicator can be expressed in three time horizons: 20, 50 and 100 years. Another method used in LCA studies is the Eco-indicator: it allows to assess the damage caused during the life cycle of a product to ecosystem quality, human health and resources.
Usually the LCA of a product/system is performed using one of the two following approaches:

- *Cradle to grave:* evaluation performed taking into account the entire life cycle of the product/service, from the extraction of the raw materials to the disposal of the product;

- *Cradle to gate*: the analysis does not consider the life of the product/service after the transportation to consumers, i.e. the use phase and the disposal.

All the environmental impacts are normalized to a functional unit, f.u., which, according to the Council for European Producers of Materials for Construction, in building thermal applications is defined as the mass in kg of material needed to have a value of thermal resistance equal to 1 m^2 K/W for a 1 m^2 panel. For this reasons CED and IPCC GWP 2007 are expressed in terms of MJ/f.u. and kg $CO_{2,eq}$/ f.u., respectively.[6]

4. Reaction to fire:

The behavior of insulation materials under fire may be responsible of serious safety issues. Several studies proved that toxic fumes are the most important causes in fire deaths; as a consequence, when selecting a building insulation, both the ignition temperature and the production of smoke should be considered. A significant reform brought about by the CE certification of technical insulation materials is that the previous national fire classifications have been replaced by European standardized fire classes.[6]
In the past, the classification of the fire behaviour reflected the national safety concept of the country in question. Although similarities in the concepts are discernable, certain aspects of the national 'fire philosophies' and test methods were very different. It was not, therefore, possible to make a direct comparison between the different building material classifications of the various countries. In 2000, a new system for classifying the fire behaviour, the limit values and the applicable testing procedures were introduced in the European Union. The classification standard EN 13501-1 distinguishes fire classes: A1, A2, B, C, D, E, F. [6]

Image	Description	Europe (European Standard EN 2)	Suitable suppression
	Combustible materials (wood, paper, fabric, refuse)	Class A	Most suppression techniques
	Flammable liquids	Class B	Inhibiting chemical chain reaction, such as water mist dry chemical or Halon
	Flammable gas	Class C	Inhibiting chemical chain reaction, such as dry chemical or Halon
	Flammable metals	Class D	Specialist suppression required
	Electrical fire	*not classified (formerly Class E)*	As ordinary combustibles, but conductive agents like water not to be used
	Cooking oils and fats	Class F	Suppression by removal of oxygen or water mist

Pic.3. Fire Europe classes. [40]

The European standard EN 13501-1 Fire classification of construction products and building elements, also defines a rating system based on diferent parameters listed in Table 4 (pic.5). And also specifies the conditions required for belonging to each class for building materials (floorings, electrical cables and pipe insulations excluded). The additional classification in EN ISO 13501-1 defines smoke development and dropping while burning. The quantity of smoke produced rises from *s1* to *s3*, while the quantity of droplets rises from *d1* to *d3*.(Pic.4) [6]

Smoke development	s3 (there are no restrictions regarding smoke development)
	s2 (the fully released amount of smoke, and the rise in smoke development, are restricted)
	s1 (stricter criteria than for s2 must be fulfilled)
Burning droplets / particles	d2 (there are no restrictions)
	d1 (burning droplets not longer than the defined time)
	d0 (dripping fire debris is not permitted)

Pic.4. Classification in EN ISO 13501-1 defines smoke development and dropping.

Table 4.
Parameters involved in reaction to fire classification [60].

Code	Brief description
DT	Temperature increase
Dm	Mass loss
Tf	Time of sustained flaming of the specimen
PCS	Gross calorific potential
FIGRA	Fire grown rate index
THR_{600s}	Total heat release
LFS	Lateral flame spread
SMOGRA	Smoke Growth Rate index
Fs	Flame spread
TSP_{600S}	Total smoke production

Pic. 5. [60] European Committee for Standardization,EN13501-1:2007A1þ2010.Fire classification of construction products and building elements—Part 1:Clas- sification using data from reaction to fire tests.

5. **Vapor resistance factor (μ-value):**

Water vapor resistance factor is a dimensionless parameter used to evaluate the vapor permeability of building insulations in comparison to the unitary value assigned to air; the higher the [*μ-value*] the lower the permeability. In addition to the water vapor resistance, also the equivalent air layer thickness [s_d] is sometimes used: it represents the equivalent thickness of air characterized by the same resistance to water vapor diffusion of the analyzed material. It is calculated by multiplying the *μ-value* with material thickness reported in meters. An insulation is considered as a vapor barrier if [s_d]>1000 –1500 [m] and as a vapor retarder if [s_d] >10 m. The *μ-value* for insulation materials can be determined by means of EN 12086 [7] and EN 12088 [8], which define the procedures to quantify the amount of water absorbed by diffusion in a longterm. [6]

1.3 Types of insulations:

There are different criteria how to sort thermal insulations [19]:

a) type of the ground substance

- inorganic,
- organic,

b) structure

- fibrous,

- porous (foam),

- granulated,

c) binder content

- containing binder,

- binder-free,

d) shape of product

- loose (back fill, wool)

- flat (board, mat, felt)

e) reaction to fire (Euroclass)

- non-combustible (class A1)

- limited combustibility (class A2, B)

- combustible (class C, D, E, F)

According to nature of the material thermal-insulating products can be divided to [20]:

a) light silicate substances – light aggregate, light concrete,

b) foam inorganic substances – foam glass,

c) foam organic substances – foam plastics,

d) fibrous substances – glass wool and mineral (stone) wool

e) organic substances – cork, timber wool, paper.

Every single type of the listed thermal insulations has its advantages and. Choice of the right insulating material should always take into account sort of the building construction and conditions in which it will serve. Due to its wide-spread and complex features. [21]

We can find nowadays a lot of different insulations. To separate them, there are two groups, traditional insulations and modern insulations.

Traditional insulations are this insulations that has been used since the fist constructions and they are still used for a lot of buildings, and they are Polytyrene expanded, Polytyrene extruded, Polyurethane, Fiberglass, Rock wool, Polyisocyanurate.

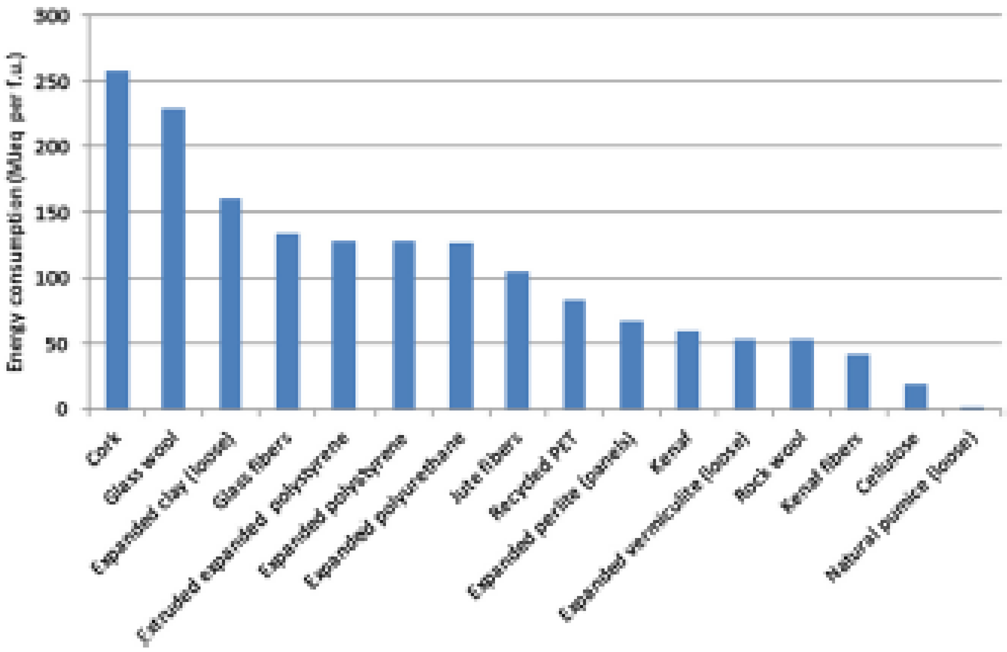
Modern insulations are ones that doing some tests during this times are also efficient or more than the traditional, and most of them are natural or with few impact in the environment are Fiberglass, Rock wool, Cellulose, Aerogels Straw bales.

Nowadays many laboratorys are doing tests to finde the most efficient and cheapest insulation.

Recently, several innovative materials and systems have been developed by researchers and manufacturers in order to obtain extremely low values of thermal conductivity together with reduced weight and thickness. Examples of these materials are vacuuminsu- lation panels, gas filled panels and aerogels. The cost of these systems and some issues, such as the uncertain service life, the poor mechanical strength and their inflexibility, still limit their wide spread diffusion in the current building market.

1.4 Sustainability with insulations:

We find another important property that consist about the energy we need to construct this insulations and it's important for the sustainability.



Pic.6 Embodied energy,interm sof MJeq per f.u.of thermal insulation material (CTGA approach).

In the last decades the attention towards energy and environmental issues has grown exponentially and many international and national policies have been developed in order to guarantee a more sustainable future to the planet, the Paris Agreement is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC) dealing with greenhouse gases emissions mitigation, adaptation and finance starting in the year 2020. The language of the agreement was negotiated by representatives of 195 countries at the 21st Conference of the Parties of the UNFCCC in Paris and adopted by consensus on 12 December 2015. [9]

Within this context, the European Union paid particular attention to the building sector, since it is responsible for 40% of the total energy consumption in Europe. Furthermore, the unrealized energy efficiency potentials in the building sector are enormous and the massive adoption of energy savings measures in this sector could represent a solution for a strong decrease of greenhouse gases emissions. Some of the aims of the Paris Agreement is: Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.The external envelope of a building plays an important role since it strongly affects the surrounding microclimate and it is a border between the internal and the external environment, influencing the thermal comfort of the inhabitants and the energy losses during the operating phase. In the context of sustainability, Life Cycle Assessment of buildings components and also of entire buildings has become more and more important, in order to take into account the whole energy uses starting from the construction up to the demolition.

The building sector is constantly innovating in its use of materials with regards to sustainability. There is a need to use cost effective, environmentally friendly materials and technologies which lessen the impact of a construction in terms of its use of non-renewable resources and energy consumption.

Currently the majority of traditional insulation materials, such as polystyrene, glass wool, and mineral wool are made from non-renewable minerals or polymers, and have a high embodied energy and global warming potential in its production.

Building insulation is commonly realized using materials obtained from petrochemicals (mainly polystyrene) or from natural sources processed with high energy consumptions (glass and rock wools). These materials cause significant detrimental effects on the environment mainly due to the production stage, i.e. use of non-renewable materials and fossil energy consumption, and to the disposal stage, i.e. problems in reusing or recycling the products at the end of their lives. The introduction of the concept of “sustainability” in building design process encouraged researches aimed at developing thermal and acoustic insulating materials using natural or recycled materials.

An alternative insulation material known as cellulose fibre insulation (CFI), has the benefit of using recycled paper to produce, while having similar performance properties to traditional insulation materials. Being made of hygroscopic fibres, it also has the benefit of acting as a moisture buffer for the control of ambient humidity in a construction.

Practical part

2. Study of traditional and modern insulations

Aim of work:

The aim of this project is to compare two different insulations, one traditional, Expanded Polystryrene, and one modern insulation, Cellulose fibers, and see their differencies, to say which is more efficient, usefull, estable, etc.

Methodology:

I would like to know how insulation works and their behaviors with thermal conductivity. For this study I choose these two insulations: Expanded polystyrene and Cellulose fibers.

1. Fisrt of all the study of their properties and how are made of. Explaining the characterisics of each insulation.

2. Later study this materials under thermal process to discover their thermal conductivity and see which is more efectivily and better for the environment, to be confortable in the building constructions.

2.1 Study of Cellulose insulation:

2.1.1 Composition Cellulose insulation:

Cellulose fibre insulation (CFI) is mainly composed of 92% ground paper fibres treated with inorganic additives that act as fire retardants and mould growth inhibitors.

Its consistency is similar to that of cotton wool. The source material for the cellulose fibres are usually recycled newspaper of other waste paper with high content of cellulose, coming from either unsold or recovered papers.

As with most lignocellulosic fibres, newsprint is comprised of a mix of cellulose hemicelluloses and lignin (% in picture 8). Mineral and organic additives, such as kaolins, straw or cationic starch are also incorporated into the paper pulp in order to improve such properties as paper opacity, moisture retention, volume and strength.

	Cellulose %	Hemicellulose %	Lignin %	Extractives %	Proteins %	Ash %
Office paper	67.4	13	0.93	0.7	0.31	11.6
Newsprint	48.3	18.1	22.1	1.6	0.44	2

Pic.8 Avarage component proportions of newspaper and office paper. [10]

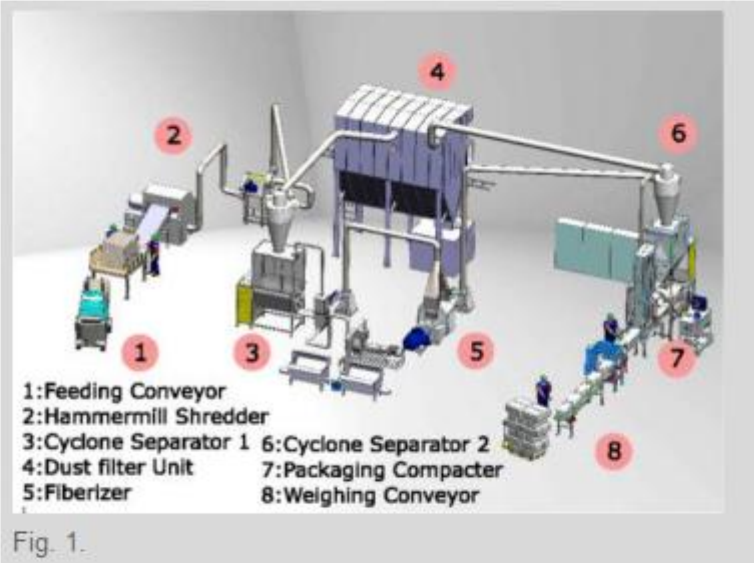
2.1.2 History:

The first use of cellulose fibre as an insulation material can be traced back to 1919 in Canada, but it was until the 1950s that commercial cellulose insulation products became commercially available in the US, where it was mostly used for attic retrofitting. CFI surged in popularity in the US in the 1970s due to an increased interest in energy performance following the American oil embargo of 1973. [11]

2.1.3 Production:

As a final product, cellulose insulation can come in two forms: as a loose fibres are sold in bulk form to be manually applied on attics, ceilings, or walls or, less commonly, the prefabricated panel, in which the cellulose fibres are moulded with polyester or a similar binder.

In a typical production process of CFI (see Pic.9), newspaper arrives in bulk to the manufacturer and is then sorted to remove any foreign objects. Items such as clips and plastics are removed, but also low quality or humid paper is also sorted. The newsprint passes through a feeding conveyor (1) then is torn to smaller pieces that are between 2 and 4 cm in diameter in a shredder (2). The fibres then pass through a cyclone separator (3) in order to remove any remaining staples or other metallic elements. The fines from the shredded paper are blown through a filtering unit (4). The material then goes through a fiberizer (5) which uses high pressured air to reduce the paper into low-density cotton-like flakes, as shown in Fig. 2. It is in this stage that the powdered additives are dispersed and mixed with the fibres. The additives used are typically a mix of borax and boric acid, with a dose of around 15%–20% of the mass of cellulose fibres. A second cyclone separator (6) then removes the fines created from the fiberizer. In the final stage of the process, the fibres are filled in bags and then mechanically compacted (7) into 3 times its normal density (around 130 kg/m^3), in order to reduce transport costs. The bags are then weighed (8) and bundled into pallets and transported to supplier or directly to construction sites. [10]



Pic.9 Example of a typical manufacturing process of CFI, adapted with permission from Makron Engineering, n.d. Fibretec 1500 production line. [41]

2.1.4 Installation of CFI:

There exist two main methods of applying CFI. Depending on the desired properties, CFI can either be installed via the "loose fill" or the "wet spray" method.

- In the **loose fill** method the cellulose fibres are installed with specific pneumatic blowing equipment. The compacted cellulose is fed to the blower which separates the fibres which then pass through the blowing system. The CFI is then delivered via air pressure into closed wall/roof cavities or attics through a hose. When cellulose is installed as "dense pack", sheets of netting are put in place over wall cavities. The cellulose is then blown into the cavities between studs at a higher density than loose fill, with the netting supporting the fibres. One of the disadvantages of this method is that settling of the material may occur over time, which decreases the insulation's effectiveness, forming voids that cause thermal bridging in a building envelope.

- The **wet spray** technique is mostly used in open-wall wood cavities separated by studs. It uses the same blowing equipment as with loose-fill CFI, but a separate pump is used to spray water simultaneously as the material is being blown with the cellulose in order to improve the adherence of the fibres. After projection the excess material is removed via a motorized wall scrubber and the excess moist material is reintegrated in the blower. The water/CFI mass ratio used in this process is typically around 40%-60%. Adhesives, either mixed with the water or dispersed within the fibres could also be used [8]. The main disadvantage of this method is that drying times may vary, depending on the thickness and ambient conditions of installation. A variant of the wet spray method is known as "stabilized" cellulose where a smaller dosage of water (less than

20% in mass) is used to prevent dust and settling in horizontal applications. [10]

2.1.5 Properties of CFI:

1. **Density and settling:**

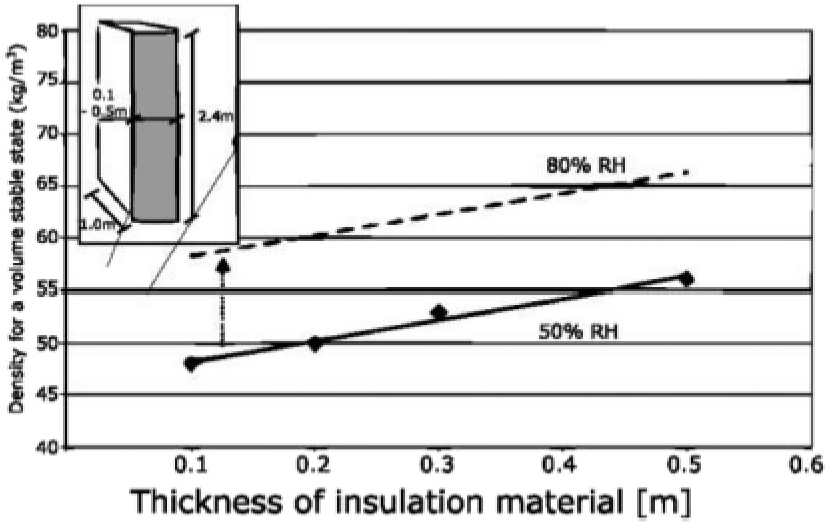
When dealing with loose fibres as an insulating material, it is important to distinguish between the "blown" density and the "design" density of the fibres. The blown density is the declared density after installation in vertical or horizontal applications, and the design density (which takes settling into account) is determined via impact testing and/or cyclic humidity testing. Impact testing consists of subjecting the loose cellulose samples to a series of vibrations. In cyclic humidity tests, the samples are subjected to periodic variations of relative humidity. One of the first studies [11] regarding the settling of CFI found an average blown density of 34.8 [kg/m^3] for horizontal applications. The average loss in thickness from settling was 21.5% wherein 10.5% was from drop impact tests and 11% was from cyclic humidity testing. The design density can be then calculated using by multiplying a factor which takes into account both types of settling:

$$Dd=(100/(100-S))Di \qquad \text{Eq.}(1)$$

Where *Dd* (kg/m^3) is the design density, *Di* (kg/m^3) is the installed density, and *S* is the sum of both the settling from drop impact tests and cyclic humidity testing.

The previous values give a design density factor of 1.27*Di*, thus an average design density of 44.4 [kg/m^3] for horizontal applications. It was also found that the dosage of fire additives increases density linearly, although the type of additive or mix thereof has little influence on final density. A survey of 38 houses in six Canadian cities [44] found the actual settling density, a year after installation, to be averaged to 11.1%, with a range of 8.3%. The study suggests that the blown density measured in laboratory be first multiplied by a factor of 1.074 to account for differences between lab and building site measurements, and then calculated with Eq. (1) using an average settling of 11.1%. [10]

For horizontal applications the compressibility of **loose-fill CFI** can make its density vary widely. One early study [42], shows installed density varying between 50 and 90 [kg/m^3]. It was recommended to increase density by 10% after filling the wall cavity in order to prevent settling, with a minimum density of 57 [kg/m^3]. A series of works by Rasmussen [43] have produced an approach which allows to analytically determine the optimal installed density of loose fill CFI that prevents settling in wood frame walls. The method takes into account the dynamic mechanical behaviour of a typical insulated wall cavity that is subjected to a cyclical variation in humidity in order to determine the density required for the fibres to lose volume. The volume stable density of CFI was determined through the study of the creep, coefficient of friction, and horizontal stress ratio testing of loose fibres. As an example, the minimum density to prevent settling with CFI a 2.4 [m] tall, 0.1 [m] thick and 1 [m] wide gypsum wall at 25 °C and 50% RH was found to be 48 [kg/m^3]. This value increases linearly with wall thickness and relative humidity (Pic. 9). Dynamic conditions were also tested, where humidity varied from 50% to 80%. In this case a 2.3 [m] high, 0.198 [m] thick and 0.495 [m] wide gypsum board cavity was calculated to require a density of 62.3 [kg/m^3] to prevent settling. This was later confirmed experimentally with a CFI-filled cavity with a density of 62.7 [kg/m^3] where settling was not observed.



Pic. 10. Calculated minimal density for settling prevention of loose fill CFI in a wall under static humidity conditions (50% and 80% RH), as a function installed thickness, top left shows the dimensions of the wall cavity [12].

For **wet spray** applications, the dry density of CFI has been shown to increase linearly with installed moisture content, ranging from 39.6 with 40% moisture content to 71.3 [kg/m^3] with 100% moisture content. If installed properly, wet spray cellulose does not settle. For stabilized cellulose, an initial moist density of around 45 [kg/m^3] gets reduced to around 38 [kg/m^3] after drying. Settling with the stabilized cellulose method in attics was found to be reduced to around 5%. [10]
Some producers has their studies and their average with density kg / m3 = 27-65. [26]

2. Thermal properties.

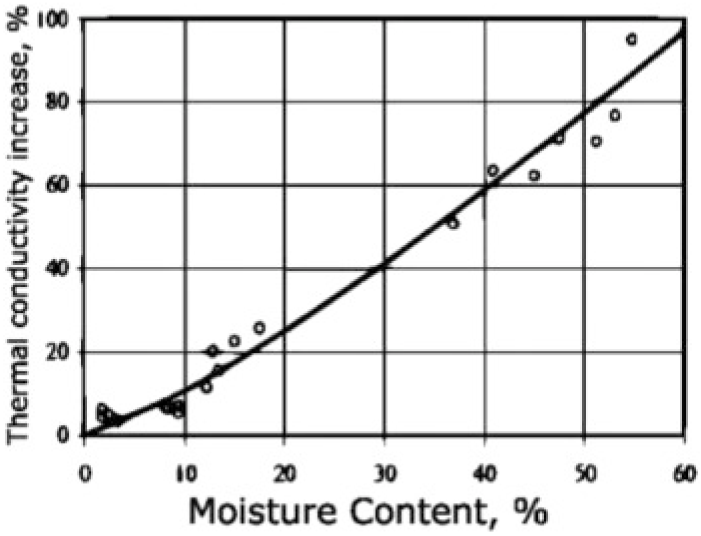
Although the typical value for CFI's thermal conductivity is around 0.040 [W/mK], its properties and performance can vary slightly depending on manufacturing and method of installation. The work of Ref. [13] has shown that a difference in the source newsprint quality can affect thermal performance. In their study, CFI samples coming from US and Korea were measured through heat flow meters. By comparing CFI from both countries, the study found that the Korean fibres that are shorter due to having gone through more recycling processes show a higher value for thermal conductivity, and therefore lower insulating performance than CFI fibres from the US.

Since cellulose fibres are naturally hygroscopic, moisture absorption can also affect thermal conductivity values. Tye and Spinney [14] studied loose fill CFI installed in ceiling and wall constructions subjected to cyclic thermal and moisture gradients. Thermal conductivity measurements were made on installed samples guarded hot box method with a mean temperature of 15 °C and a temperature difference of approximately 10 °C. It was found that thermal conductivity increased by 15% for a moisture gain of 10%. Nicolajsen [15] found that under the hygroscopic range (RH <90%) the change in thermal transmittance of loose fill cellulose insulation within a wall cavity was not significant (1%–3% increase). The study was done on facade elements with 285 [mm] loose-fill CFI equipped with heat flow meters and moisture measuring dowels. Heat flow measurements were made according to the DS 418 standard. Sandberg [16] developed three approaches to determine thermal conductivity as a function of water absorption using moisture content profiles of cellulose insulation. Measurements were made on 164 [mm] thick loose fill CFI samples on 600 [mm] × 600 [mm] frames, following the ISO 8301 and ISO DIS10-051 standards. Computer simulations used the following relation with regards to the thermal conductivity of cellulose:

$$\lambda = 0.037 + 0.0002' \ w(\mathrm{W/mK}).$$

Where *w* is the mass of water per unit volume of cellulose [kg/m^3]. The calculated results were in agreement with sample measurements.
Talukdar et al. [17] determined a polynomial function to describe the relation between moisture and thermal conductivity by curve fitting values measured by a heat flow meter apparatus according to ASTM standard C518 on cellulose at different relative humidity conditions. Measurement temperatures were at 10 °C and 350 ºC, with an average temperature of 22.5 °C

The only research that studied changes in thermal conductivity past the hygroscopic range was done by Vèjelis et al. [18] Their study determined moisture content of CFI in one - and two floor buildings with masonry walls with different thickness of insulation throughout various moisture periods measurements. A qualitative method was used to determine the influence of moisture on variations in thermal conductivity. An increase in 1% of moisture content can lead to an average increase of 1.2%–1.5% in [*λ*] values for loose-fill CFI. Even when high moisture content was reached, thermal conductivity increased from 1.6 to 2.0% for 1% of moisture content (Pic.11). These changes in values of [*λ*] are similar to those mentioned previously in the hygroscopic range. Generally for the hygroscopic range, the increase in thermal conductivity could be considered negligible. It is only when capillary moisture begins (RH > 90%) where the insulating properties would be ineffective. Such cases could arrive due to rain infiltration, leaking pipes, or improperly installed wet spray cellulose.



Pic 11. Increase in thermal conductivity with moisture content of cellulose fibre insulation [18].

Some producers [26] has their own values for differents characteristics:

- Thermal conductivity/ λ (lambda) W/ m.K = 0.035 in lofts; 0.038 - 0.040 in walls.
- Thermal resistance at 100mm K·m2/W = 2.632.
- Specific Heat Capacity J/(kg.K)= 2020.

3. Moisture properties:

The behaviour of a building material with moisture can be determined by a series of intrinsic parameters. The sorption isotherm of a material can determine amount of water absorbed under different values of relative humidity. This series of values is usually measured through continuous weighing of a cellulose insulation sample subjected a series of changes in humidity via saturated salt solutions.

Moisture diffusivity, is a property that is used in simulations to determine the moisture concentration profile of a material. It is defined by the moisture transport equation:

$$J_m = -\rho.D.grad\ u$$

With [*Jm*] = moisture flux [kg/m²s], [*ρ*] the dry density of the material [kg/m3], and [*u*] the moisture content [kg/kg].

The highly hygroscopic nature of cellulose insulation can be detrimental to CFI's performance, as was shown with the two previous sections. However having a hygroscopic material in a building envelope could theoretically be beneficial when it comes to regulating humidity conditions inside a building, especially if a vapour retarder is not integrated in the building envelope.

For wet spray cellulose, drying is an important factor to consider during installation. The water from the sprayed fibres could be transmitted to wood frames cavities which could cause warping or mould growth.
Drying of wet spray CFI with a hygrothermal model that takes into account the period of installation. The study compared drying in a region with warm dry climate vs. a region with cold humid climate. It was found that for winter months the wet spray CFI would take many weeks to dry and in some cases not dry at all, especially in colder region.

During the winter months of November, December, and January moisture content decreased by only 10% in a month. The wet spray method is therefore preferred to be applied in warmer drier climates.

4. Air permeability:

Air permeability study is important because it can cause judicial and have an impact on energy loads in buildings.

The study done by Boonyakarn et al. [22] found that the installation of CFI (wet-spray in walls and loose-fill in attics) reduced the air change rate from 87.5 to 29.4 ACH (Air changes per hour) with 50 Pa blower door testing. CFIwas found to improve air tightness 36% better than fibreglass.

The difference in air permeability between types of insulation is negligible once aweather barrier was applied.

5. Fire properties:

The high flammability of cellulosic fibres, would not support combustion, so requires them to be treated before installation in order to achieve better levels of combustion and smouldering resistance. Cellulose is dense material that is relatively impervious to flames and gases. Because of this, and the fire retardance of the material, fire does not spread as readily into cellulose-insulated walls or ceilings. Walls insulated with cellulose don't readily become draft chambers that deliver oxygen to burning framing members. Cellulose greatly restricts the amount of oxygen available to support combustion in insulated assemblies. The ceiling of a cellulose-insulated structure remained intact for 70 minutes.[23]

In a typical CFI material, borate salts are added to prevent combustion and boric acid is added to prevent smouldering, while the flame was applied the insulation fibers glowed, but when the flame was removed, immediately the combustion process stopped.
Other additives include aluminium sulphate, aluminium trihydrate, ammonium phosphate, and ammonium sulphate.
The minimum boric acid required to prevent smouldering as a function of borax dosage was established:

$$\text{boric acid required} = 11.6 + 0.185 \times (\text{borax used}).$$

Pic.12. function to determine the minimum of boric acid[10]

Day et al. [24] found that the optimal borax/boric acid ratio of 1/8 with a dosage 16% is necessary to prevent both flaming and smouldering combustion.

A three component formulation using borax, boric acid, and aluminium sulphatewas also studied. Varying dosage from 12% 18% and 24% increases the possible proportions of these constituents which allow both smouldering and combustion resistance to be obtained. [10]

6. Fungal development.

It is known that wet lignocellulosic materials can allow mould growth. In the case of CFI, the added additives can serve a dual purpose of preventing mould growth as well as fire propagation.
In the work of [25]; it was found that the boron included in the cellulose was found to have a sporocidal effect on five of the most common types of fungal spores, even when subjected to a high concentration of fungi.
For untreated fibres exposed to fungal samples, moisture content and relative humidity was found to have an influence on the fungal growth rate of cellulose insulation. As the CFI samples dried, the rate of mould growth decreased.

7. Life cycle analysis.

Life cycle assessment is a useful tool in material selection for construction projects.
CFI has a low embodied energy compared to traditional mineral and natural insulation materials.

Since the materials have different densities and thermal conductivities, a more proper functional unit would be the necessary amount of material to provide a specific value of thermal resistance.

Embodied energy MJ/kg = 0.45 [26]

	Building product density (kg/m^3)	Thermal conductivity (W/mK)	Primary energy demand (MJ-Eq/kg)	Global warming potential (kg CO_2-Eq/kg)	Water demand (l/kg)
EPS foam slab	30	0.0375	105.486	7.336	192.729
Rock wool	60	0.04	26.393	1.511	32.384
Polyurethane rigid foam	30	0.032	103.782	6.788	350.982
Cork slab	150	0.049	51.517	0.807	30.337
Cellulose fibre	50	0.04	10.487	1.831	20.789
Wood wool	180	0.07	20.267	0.124	2.763

Pic. 13. Comparative life cycle analysis of common building materials [27].

2.1.6 Advantages and disadvantages

We find advantages and disadvantages in the properties of the cellulous insulation [28].

Advantages:

1. Thermal performance:
   The thermal performance of loose filled cellulose compares favorably to other types of low cost insulation, but is lower than that of polyurethane and polyisocyanurate foams. The thermal conductivity of loose-fill cellulose is approximately 0.04 W/mK, which is about the same as or slightly better than glass wool or rock wool. This doesn't represent the whole picture of thermal performance.

2. Long-term cost savings:

   Annual savings from insulating vary widely and depend on several factors, including insulation thickness, original wall performance, local climate, heating/cooling use, airtightness of other building elements and so on.

   One installer claims cellulose insulation "can save homeowners 20 to 50 percent on their utility bills"

3. Sound insulation:
   Cellulose provides mass and damping. This reduces noise in 2 ways, it reduces the lateral movement of sheetrock and attenuates the passage of

sound along cavities. Cellulose is approximately three times denser than fiberglass, providing a slight improvement in sound reduction.

4. Mold and pest control:
   The borates in cellulose insulation provide added control against mold. Installations have shown that even several months of water saturation and improper installation did not result in mold. It is a common misconception that the mere presence of crude borates in cellulose insulation provides pest control properties to the product. While boric acid itself does kill self-grooming insects if ingested, it must be presented to an insect in both sufficient concentration and in an ingestible form in order to achieve insect fatality.

5. Fire retardation:
   The borate treatment also gives cellulose the highest (Class I) fire safety rating. Many cellulose companies use a blend of ammonium sulfate and borate.

6. Vapor barrier:
   An insulation that fills the wall cavity completely (such as cellulose or foam) can help prevent moisture problems. Recommendations against using vapor barriers with cellulose insulation are supported by studies, even though they classify cellulose as vapor permeable. [29]

Disadvantages:

1. Dust:
   Cellulose contains small particles which can be blown into the house through inadequate seals around fixtures or small holes:

2. Slumping:
   If improperly installed, loose fill cellulose could settle after application. In some situations this could leave areas of wall uninsulated. With correct training in installation methods and quality control techniques this is ruled out by installing to tested densities preventing any future settlement.

3. Weight:
   For a given R-value, loose cellulose weighs roughly three times as much per square foot as loose fiberglass.

4. Offgassing:
   Many cellulose companies use a blend of ammonium sulfate and borate for fire retardation. Although ammonium sulfate is normally odorless, unexplained emission of ammonia and a resulting ammonia smell has been found in some cases.

5. Mold:
   There is some evidence of increased mold infestation inside buildings insulated with wet spray dense pack cellulose especially when used with a vapor barrier.

2.2 Study of EPS (Expanded Polystyrene) insulation:

2.2.1 Composition:

The EPS industry holds a marketshare of 35% of the total insulation market for construction in Europe. EPS has been a well performing and sustainable insulating material over the past 60 years.

Expanded polystyrene (EPS) is a synthetic aromatic polymer made from the monomer styrene is rigid cellular plastic material manufactured by moulding beads of expandable polystyrene or one of its copolymers and which has a substantially closed cell structure, filled with air [34]. Polystyrene can be solid or foamed. General-purpose polystyrene is clear, lightweight, hard, and rather brittle, closed-cell foam. It is an inexpensive resin per unit weight. It is a rather poor barrier to oxygen and water vapor and has a relatively low melting point. Polystyrene is one of the most widely used plastics, the scale of its production being several billion kilograms per year. Polystyrene can be naturally transparent, but can be colored with colorants.

Expanded polystyrene (EPS) is commonly used in a variety of applications because of its features of light weight, good thermal insulation, moisture resistance, durability, acoustic absorption and low thermal conductivity. It has been increasingly used in building constructions as core material of structural insulated panels (SIP). Some of those structures during their service life may be subjected to dynamic loads such as accidental or hostile explosion loads and windborne debris impacts. Understanding the dynamic material properties of EPS is essential for reliable predictions of the performances of the structural insulated panels with EPS foam core material. This paper [30] presents static and dynamic compressive and tensile test data of EPS with density 13.5 [kg/m^3] and 28 [kg/m^3] at different strain rates. The dynamic strength, Young's modulus and energy absorption capacities of the two EPS foams at different strain rates are obtained and presented in the paper. Based on the testing data, some empirical relations are derived, which can be used to model EPS properties in numerical simulations of dynamic responses of structural insulated panels with EPS foam core subjected to impact and blast loads.[30]

2.2.2 History:

Polystyrene was discovered in 1839 by Eduard Simon, an apothecary from Berlin. From storax, the resin of the American sweetgum tree Liquidambar styraciflua, he distilled an oily substance, a monomer that he named styrol. Several days later, Simon found that the styrol had thickened into a jelly he dubbed styrol oxide ("Styroloxyd") because he presumed an oxidation.

By 1845 Jamaican-born chemist John Buddle Blyth and German chemist August Wilhelm von Hofmann showed that the same transformation of styrol took place in the absence of oxygen. They called the product "metastyrol"; analysis showed that it was chemically identical to Simon's Styroloxyd. In 1866 Marcelin Berthelot correctly identified the formation of metastyrol/Styroloxyd from styrol as a polymerization process. About 80 years later it was realized that heating of styrol starts a chain reaction that produces macromolecules, following the thesis of German organic chemist Hermann Staudinger (1881–1965). This eventually led to the substance receiving its present name, polystyrene.

The crystal structure of isotactic polystyrene was reported by Giulio Natta.

In 1954, the Koppers Company in Pittsburgh, Pennsylvania, developed expanded polystyrene (EPS) foam under the trade name Dylite.

In 1988, the first U.S. ban of general polystyrene foam was enacted in Berkeley, California. [31]

2.2.3 Production:

Polystyrene foams are produced using blowing agents that form bubbles and expand the foam. In expanded polystyrene the expansion is achieved by virtue of small amounts of pentane gas dissolved into the polystyrene base material during production. The gas expands under the action of heat, applied as steam, to form perfectly closed cells of EPS, these are usually hydrocarbons such as pentane, which may pose a flammability hazard in manufacturing or storage of newly manufactured material, but have relatively mild environmental impact. These cells occupy approximately 40 times the volume of the original polystyrene bead. The EPS beads are then moulded into appropriate forms suited to their application.

2.2.4 Manufacturing process

The manufacture of EPS conforms to the most stringent health and safety requirements in Europe.

There are 5 manufacturing stages:

1) **Pre-expansion:**
Polystyrene granules are expanded by free exposure to steam to form larger beads, each consisting of a series of non-interconnecting cells.

2) **Conditioning:**
After expansion, the beads still contain small quantities of both condensed steam and pentane gas. As they cool, air gradually diffuses into the pores, replacing, in part, the other components.

3) **Moulding:**
The beads are moulded to form boards, blocks or customised products. The mould serves to shape and retain the pre-foam, and steam is again used to promote expansion. During moulding, the steam causes fusion of each bead to its neighbours, thus forming a homogeneous product.

4) **Shaping:**
Following a short cooling period, the moulded block is removed from the machine, and after further conditioning, may be cut or shaped as required using hot wire elements or other appropriate techniques.

5) **Post-production processing:**
The finished product can be laminated with foils, plastics, roofing felt, fibreboard or other facings such as roof or wall cladding material.

2.2.5 Material properties:

The properties of EPS insulation materials for buildings and their test methods are defined in EN 13163, which is mandatory since 13 May 2003 for all EU countries. EN 14933 is the relevant standard for civil engineering applications. Further standards are under development, such as for installed equipment. These harmonised European standards include of a list of properties and test methods, both for general and for specific applications. [32]

1. **Thermal conductivity.**

   Is measured according to EN 12667 and ISO 13163, ISO 12939. Typical values range from 0.032 to 0.038 [W/m·K] depending on the density of the EPS board. The value of 0.038 [W/m·K] was obtained at 15 [kg/m^3] while the value of 0.032 [W/m·K] was obtained at 40 [kg/m^3] according to the data sheet of K-710 from StyroChem Finland. [31]

   Adding fillers (graphites, aluminium, or carbons) has recently allowed the thermal conductivity of EPS to reach around 0.030–0.034 (as low as 0.029) and as such has a grey/black color which distinguishes it from standard EPS. Several EPS producers have produced a variety of these increased thermal resistance EPS usage for this product in the UK & EU.[31]

EPS TYPE	EN 13163	[unit]	EPS 60	EPS 100	EPS 150	EPS 200	EPS 250
Thermal conductivity	EN 12667 or EN 12939	"Lambda" mW/m^{0}K	38	36	35	34	34
Compressive stress 10%	EN 826	CS(10) kPa	60	100	150	200	250
Bending strength	EN 12089	BS kPa	100	150	200	250	350
Dimensional stability	EN 1603	DS(N) %	0,5%	0,5%	0,5%	0,5%	0,5%
Approximate Density		kg/m^3	**15**	**20**	**25**	**30**	**35**

Pic 14. EPS product types without intended specific application [32].

2. Vapor diffusion.

The resistance of water vapor diffusion [*μ*] of EPS is around 30–70.

EPS boards used in building construction meet ISO 9705 standards. Eps vapor resistance can vary in intensity to the desired range, both externally and offers convenient options for thermal insulation applications both from inside.[45]

Water vapour permeability shall be determined in accordance with ISO 1663 under one of the following sets of test conditions indicated in the ISO1663 [34]:
a) 38 °C / 0 % to 88,5 % RH;
b) 23 °C / 0 % to 50 % RH.

3. Fire.

EPS behaviour with fire is at least quickly for his plastic composition, but also have retardands to change his time of burned and smouthering.
The same classes that in CFI classification.

4. Density of EPS.

Density measurement is optional for all materials in countries where a system of class identification has been established. Density shall be

determined in accordance with ISO 1602 on each of ten full-size boards and reported as the average of the ten specimens.
The average density of the ten specimens shall be equal to or greater than the minimum required and no single specimen shall be less than 90 % of the minimum requirement. When the natural skin of the material forms an integral part of the product in its end use, the surface skin shall not be removed prior to the determination of the density. For those materials with surface facing, lamination or coating, the density shall be determined for the core material after removing such facing, lamination or coating [34].

The density range is 10-50kg/m3 The EPS types shown below. Nominal Densities [35]:

EPS 70 - 15kg/m3

EPS 100 - 20kg/m3

EPS 150 - 25kg/m3

EPS 200 - 30kg/m3

EPS 250 - 35kg/m

5. **Waterproof.**

Although it is a closed-cell foam, both expanded and extruded polystyrene are not entirely waterproof or vaporproof. In expanded polystyrene, water absorption shall be determined in accordance with ISO 2896 there are interstitial gaps between the expanded closed-cell pellets that form an open network of channels between the bonded pellets, and this network of gaps can become filled with liquid water. If the water freezes into ice, it expands and can cause polystyrene pellets to break off from the foam. [34]

6. **Waterlogging.**

Commonly occurs over a long period of time in polystyrene foams that are constantly exposed to high humidity or are continuously immersed in water, such as in hot tub covers, in floating docks, as supplemental flotation under boat seats, and for below-grade exterior building insulation constantly exposed to groundwater. Typically an exterior vapor barrier such as impermeable plastic sheeting or a sprayed-on coating is necessary to prevent saturation.

7. **Biodegrade.**

Discarded polystyrene does not biodegrade for hundreds of years and is resistant to photolysis. Non recycling and non-incineration.

Property	Unit	Category (see 5.1) and subcategory (see 5.2)							Test method
		I	II		III			IV	
			A	B	A	B	C		
Density (min.)[a]	kg/m^3	15	20	20	30	30	30	30	ISO 845
Compressive strength or compressive stress at 10 % deformation or yield (min.)	kPa	50	100	100	150	150	150	250	ISO 844
Thermal conductivity (max.)									
10 °C mean/28 days min.	mW/(m·K)	37	34	37	28	32	37	25	ISO 8301 or ISO 8302
or									
23 °C mean/28 days min.	mW/(m·K)	39	36	39	29	34	39	26	
Dimensional change after 48 h at 70 °C (max.)	%	5	5	5	5	5	5	5	ISO 2796 as modified in 8.5
Compressive creep (max.) after 48 h at 80 °C under 20 kPa load	%	—	5	5	—	—	—	—	ISO 7616 or ISO 7850 as modified in 8.6.1
Compressive creep (max.) after 7 days at 70 °C under 40 kPa load	%	—	—	—	5	5	5	5	ISO 7616 or ISO 7850 as modified in 8.6.2
Water vapour permeability[b] 23 °C/0 % to 50 % RH	ng/(Pa·s·m)	9,5 to 3,5	4,5 to 0,5		2,0 to 0,5		4,5 to 1,0	4,5 to 1,0	ISO 1663
Water absorption (max.)	% by volume	6	4	4	2	2	2	2	ISO 2896
Bending load at break (min.)	N	15	25	25	35	35	35	35	ISO 1209-1 as modified in 8.8

[a] Density is optional in a country that has established a system of class identification.

[b] A specific limiting value (maximum or minimum, depending on the application) may be selected by agreement between purchaser and supplier.

Pic.15 Required properties of EPS used for thermal insulation of buildings [34]

2.2.6 Advantages and disadvantages

We find advantages and disadvantages in the properties of the EPS insulation.

Advantages [38]:

1. Light: bulk EPS density of Chinese standard is 18~22kg/m3, but the people only using EPS board 15kg/m3 in Europe.
2. Low thermal conductivity: Because of the air filled hole group structure, prevent the spread of air, the heat conduction coefficient is under 0.039.
3. Because 98% of foam insulation board space is filled with air, have sufficient capacity to buffer the impact of the outside world and by changing the shape, good anti impact ability.
4. Low water absorption. Studies have shown that humidity will affect the thermal and mechanical properties, low water absorption materials help to maintain these properties.
5. Recyclable: The recovery degree is the highest in plastics.

6. The production process does not apply Freon.

7. The full life cycle energy consumption of plastics in the lowest.

Disadvantages [38]:

1. Need to hang nets, complex construction, long construction period.

2. Flammable, toxic, ordinary polystyrene foam insulation board is easy to burn, toxic combustion fumes, even after the combustion of flame retardant, it can only reach B. The external wall insulation fire, polystyrene foam insulation board accounted for 95%.

3. Material strength is poor, prone to cracking and falling insulation phenomenon.

4. Polystyrene foam insulation board because of its limited strength, load-bearing ability, tiles need to strengthen treatment.

5. Polystyrene foam insulation board quality is not stable, because materials factory need to place for a period of time, after a period of maturity before they can be used, if not thoroughly cooked, the quality will not be guaranteed, resulting in foam shrinkage cracking.

3. Data of thermal conductivity in EPS and CFI

4. Comparation

I can see similituds and differences between this two insulations but the most characterization are the thermal confort that is higher in the EPS insulations, the difference is that the R-value is less in CFI, EPS 5.5 R-value and CFI 3.8 R-value, and the other is the energetic costs that cellulose fibers, 5 kW/h, needs less energy to produce this kind of insulations than EPS 165.66 kW/h.

The advantages of polystyrene foam insulation board is more, but the disadvantages are more deadly. At present, the market has been gradually polystyrene foam insulation board elimination tendency. There is a lot of new external insulation materials in the current market, resulting in a large number of waste EPS foam, if handled improperly, can easily cause white pollution.

In the other way, CFI is an innovative eco-friendly insulation material that presents similar characteristics in terms of thermal comfort and performance to its non-renewable counterparts. Nevertheless the material presents some disadvantages compared to less eco-friendly insulation materials and has shown the need for more optimization and development. Further research needs to focus on studying and resolving the issues with the material's properties and performance.

First of all there needs to be a better understanding of the source material. While the available research has been shown on the performance of CFI after installation, more work needs to be done on the manufacture and installation methods in order to further optimize the material. Studying this can be difficult due to the fact that CFI manufacturers have many suppliers for newsprint, each of whom may use different compositions of paper and methods of manufacture. Nevertheless, knowing the properties of the source newsprint in terms of paper quality, composition, fibre morphology, and their influence on CFI insulation quality will help reduce variability in the performance of CFI.

For loose fill CFI, novel methods need to be developed to reduce settling, especially in horizontal applications. How material separation and blowing speed during installation can affect these factors has yet to be analyzed. The stabilized approach needs to be further developed to study the influence of water on dust exposure, density and settling. This also applies to the wet spray method, where the role of water dosage on the final properties of cellulose should be investigated.

Finally changes in the formulation of CFI could be envisioned. Other, more environmentally friendly additives with antifungal or fire retardant properties could replace some or all of the mineral additives used currently. The incorporation of adhesives and tackifiers in the wet-spray method has been known to be used by some manufacturers of CFI but their effect on the fibres and the performance of CFI has not yet been quantified.

It is through these innovations that cellulose fibre-based insulations can become more prevalent and contribute to more eco-friendly construction projects.

5. Conclusions:

My conclustions about the final project is that nowadays the industry is innovating and every day are new insulations or mixed insulations to find the most effectively.

For me the cellulose insulation apart from the low difference between the thermal conductivity with EPS, is more efficiently and contributes to mantenaince the world green and is cheaper because the thermal conductivity is less. Also the Cellulose insulations are created with recyclable papers, and at the present time is mixed with for example straw

that improve his properties to react better to each characteristics needed in each moment.
Continuous with that, the insulations have many types and materials to create many, so that it will be good the thikness with the higher thermal resistence or introduce differents materials to innovate or at the end to innovate with the constructions we are creating.

I would like to say thank you to my supervisor Jiri Zach, for be patient with me and my final project, and to understand my situation, also thank you to my family always supporting me, Xavi my college that has been during all my carreer with me and helping me, my mates in Erasmus, and the teachers that give me all the knowledges that now I know during this years for the future.

6. References:

[1] The properties of cellulose insulation applied via the wet spray process. Pablo Lopez Hurtado, Antoine Rouilly, Christine Raynaud,Virginie Vandenbossche. 2016.

[2] *Renewable and Sustainable Energy Reviews*, 2016, vol. 62, issue C, pages 988-1011.

[3] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings.

[4] Measurement of dynamic stiffness to estimate the reduction in impact sound pressure level Andrea Pavoni Bellia , Francesco Russoa , Alessandro Schiavia a Istituto Elettrotecnico Nazionale Galileo Ferraris – Torino.

[5] Acoustic characterization of natural fibers for sound absorption applications. Umberto Berardi, Gino Iannace.2015

[6] Insulation materialsforthebuildingsector: A review and comparative analysis S. Schiavoni , F.D'Alessandro , F.Bianchi, F.Asdrubali. 2016

[7] European Committee for Standardization, EN 12086:2013. Thermal insulat- ing products for building applications. Determination of water vapour transmission properties.

[8] European Committee for Standardization,EN12088:2013.Thermal insulat-ing products for building applications — determination of longterm water absorption by diffusion.

[9] https://en.wikipedia.org/wiki/Paris_Agreement

[10] A review on the properties of cellulose fibre insulation; Pablo Lopez Hurtado , Antoine Rouilly, Virginie Vandenbossche, Christine Raynaud.

[11] M. Bomberg, C.J. Shirtliffe, Comments on standardization of density and thermal resistance testing of cellulose fibre insulation for horizontal applications, Build. Res. Note 147 (1979) 17.

[12] T.V. Rasmussen, Modelling settling of loose-fill insulation in walls, part II determination of coefficients, J. Build. Phys. 25 (2002) 189e208, http://dx.doi.org/10.1177/0075424202025003605.

[13] Y.C. Kwon, D.W. Yarbrough, A comparison of Korean cellulose insulation with cellulose insulation manufactured in the United States of America, J. Therm. Envelope Build. Sci. 27 (2004) 185e197, http://dx.doi.org/10.1177/1097196304035242.

[14] R.P. Tye, S.C. Spinney, A study of the effects of moisture vapour on the thermal transmittance characteristics of cellulose fibre thermal insulation, J. Build. Phys. 2 (1979) 175e196, http://dx.doi.org/10.1177/109719637900200402.

[15] A. Nicolajsen, Thermal transmittance of a cellulose loose-fill insulation material, Build. Environ. 40 (2005) 907e914, http://dx.doi.org/10.1016/j.buildenv.2004.08.025.

[16] P.I. Sandberg, Determination of the effects of moisture content on the thermal transmisivity of cellulose fiber loose-fill insulation, in: Thermal Performance of the Exterior Envelopes of Building III, ASHRAE/DOE/BTECC/CIBSE Conference 517e25, 1992.

[17] P. Talukdar, O.F. Osanyintola, S.O. Olutimayin, C.J. Simonson, An experimental data set for benchmarking 1-D, transient heat and moisture transfer models of hygroscopic building materials. Part II: Experimental, numerical and analytical data, Int. J. Heat Mass Transf. 50 (2007) 4915e4926, http://dx.doi.org/10.1016/j.ijheatmasstransfer.2007.03.025.

[18] S. V_ejelis, I. Gnipas, V. Ker_sulis, Performance of loose-fill cellulose insulation, Mater. Sci., (MED_ZIAGOTYRA) 12 (2006).

[19] EN 13162 (2001), Thermal insulation products for buildings – Factory made mineral wool (MW) products – Specification. Brussels: European Committee for Standardization, pp 8-23

[20] Svoboda L., Tobolka Z. (1996), Stavební izolace 1,2 – Materiály. Praha: Vydavatelství ČVUT, pp 45-47

[21] Impact of moisture on long term performance of insulating products based on stone wool; Tomáš Vrána; Licentiate Thesis; Stockholm; September 2007.

[22] S. Boonyakarn, D. Arch, S.R. Spiezle, Fibreglass Vs Cellulose Installed Performance, 1990.

[23] Assuring an abundant oxygen supply; http://www.houleinsulation.com/fire.html.

[24] M. Day, T. Suprunchuk, D.M. Wiles, The fire properties of cellulose insulation, J. Build. Phys. 4 (1981) 157e170, http://dx.doi.org/10.1177/109719638100400301.

[25] J. Herrera, Assessment of fungal growth on sodium polyborate-treated cellulose insulation, J. Occup. Environ. Hyg. 2 (2005) 626e632, http://dx.doi.org/10.1080/15459620500377667.

[26] Warmcel and others; http://www.greenspec.co.uk/building-design/insulation-materials-thermal-properties/.

[27] I. Zabalza Bribi_an, A. Valero Capilla, A. Aranda Us_on, Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential, Build. Environ. 46 (2011) 1133e1140, http://dx.doi.org/10.1016/j.buildenv.2010.12.002.

[28] Cellulose insulation; https://en.wikipedia.org/wiki/Cellulose_insulation#cite_note-8

[29] Applegate Insulation, letter on recommendation regarding vapor retarders, "Archived copy" *(PDF). Archived from* the original *(PDF) on 2006-05-11*. Retrieved 2008-04-18*.*

[30] Static and dynamic mechanical properties of expanded polystyrene. Wensu Chen, Hong Hao, Dylan Hughes, Yanchao Shi, Jian Cui, Zhong-Xian Li ; 2014.

[31] Polystyrene. https://en.wikipedia.org/wiki/Polystyrene

[32] Eumeps; http://www.eumeps.construction/technical_properties_4950.html?psid=ec99gqb0d194uk3ip7tp60c5t2

[33] Fire Properties of Wall and Ceiling Linings: Investigation of Fire Test Methods for Use in NZBC Compliance Documents. PCR Collier, PN Whiting and CA Wade; STUDY REPORT No. 160 (2006); the Building Research Levy, the Department of Building and Housing (DBH), and Plastics New Zealand Inc. http://www.branz.co.nz/cms_show_download.php?id=7652db415e65acf4391dcaffb8edb87fac3784ff

[34] Rigid cellular plastics — Thermal insulation products for buildings — Specifications; ISO 4898:2010. file:///F:/final%20project/standard5697.pdf

[35] EPS technical information; Jabalite; Vancel Resil http://www.isoclad.co.uk/pdf/EPS_Datasheet.pdf

[36] Information about EN ISO 4589-2 Oxygen Index**;** EN ISO 4589-2, Determination of burning behaviour by oxygen index. https://www.sp.se/en/index/services/vehicles/iso4589-2/Sidor/default.aspx.

[37] Fire and cellular polymers; J.M. Buist, S.J. Grayson, W.D. Woolley; Elsevier Aplaied Science. https://books.google.es/books?id=PdTsCAAAQBAJ&pg=PA120&lpg=PA120&dq=oxygen+index+of+EPS+iso+4589&source=bl&ots=KiEciX1VKN&sig=m11vh7lXmazXw35XnCYdcJ8Tqgc&hl=ca&sa=X&redir_esc=y#v=onepage&q=oxygen%20index%20of%20EPS%20iso%204589&f=false

[38] http://www.styrofoamdensifier.org/the-advantages-and-disadvantages-of-polystyrene-foam-insulation-board/

[39] http://www.smarterhomes.org.nz/design/insulation/.

[40] https://en.wikipedia.org/wiki/Fire_class

[41] Makron Engineering, n.d. Fibretec 1500 production line.

[42] M. Bomberg, K.R. Solvason, How to ensure good thermal performance of cellulose fiber insulation. Part II. Exterior walls, J. Build. Phys. 4 (1980) 119e133, http://dx.doi.org/10.1177/109719638000400204.

[43] T.V. Rasmussen, Prediction of density for prevention of settling of hygroscopic and nonhygroscopic loose-fill insulation in walls, J. Therm. Envelope Build. Sci. 28 (2005) 245e267, http://dx.doi.org/10.1177/1097196305048596.

[44] R. Zaborniak, Prediction of long-term density of cellulose fibre insulation in horizontal spaces of new residential houses, J. Build. Phys. 13 (1989) 21e32, http://dx.doi.org/10.1177/109719638901300104.

[45] http://www.karplus.com.tr/EN/xpsandepscomparison.html