Proceedings of the IASS 2024 Symposium
Redefining the Art of Structural Design
August 26-30, 2024, Zurich Switzerland
Philippe Block, Giulia Boller, Catherine DeWolf,
Jacqueline Pauli, Walter Kaufmann (eds.)

Climate friendly insulation based on biobased products for IASS 2024

Arno D.C. PRONK*

*Arno D.C. Pronk
Vertigo 9.35 Postbus 513 5600 MB
EINDHOVEN
a.d.c.pronk@tue.nl

Abstract

This report addresses the potential of utilizing biobased insulation materials as a substitute for insulation in the cavity of new built residential buildings. Due to the sustainability ambitions of both parties, the question arose how to insulate the residential building more sustainably. Biobased products are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised". The reason for using biobased materials lays in their potential to make economy more sustainable and to lower the dependence on fossil fuels. Métisse is a biobased material. The current market offers little biobased insulation materials that can be used in a cavity. The biobased materials that do exist are more often used in renovation projects rather than new construction projects. In addition, moisture management can become a problem since biobased materials have different moisture absorption properties compared to traditional insulation. Lastly, onsite construction processes, including weather exposure, can influence the performance of biobased materials. To address these challenges effectively, it is essential to identify and understand the potential problems that may arise when biobased insulation material is being used. From several biobased materials, the properties and pros and cons are elaborated according to basic criteria. Hereafter, a score card (multicriteria analysis) is made which elaborates on all materials related to the criteria. Out of the score card, the three best materials are found which can be used as replacement of insulation in the traditional cavity wall.

Keywords: improvement of biobased insulation to avoid moister

This report addresses the potential of utilizing biobased insulation materials as a substitute for insulation in the cavity of new built residential buildings. This report would like to realize 27 homes in the city centre of Eindhoven at the Sint Catharinastraat. The following figure illustrates the location context of this project site.

Figure 1 The Hazenberg Sint Catherinastraat project site in the city center of Eindhoven

Due to the sustainability ambitions of both parties, the question arose how to insulate the residential building more sustainably. More specifically, the main task lies in finding out what biobased insulation would pose a more sustainable and economically more lucrative solution as opposed to glass wool- the currently chosen insulation material in the cavity. Glass wool is placed in the masonry cavity walls which are mainly situated at the front and back façades. Biobased materials in the project are defined based on the European Commission (n.d.) definition of biobased projects: “Biobased products are wholly or partly derived from materials of biological origin, excluding materials embedded in geological formations and/or fossilised”. The reason for using biobased materials lays in their potential to make economy more sustainable and to lower the dependence on fossil fuels. Different insulation materials have been compared. The current market offers little biobased insulation materials that can be used in a cavity. The biobased materials that do exist are more often used in renovation projects rather than new construction projects. In addition, moisture management can become a problem since biobased materials have different moisture absorption properties compared to traditional insulation. Lastly, onsite construction processes, including weather exposure, can influence the performance of biobased materials. To address these challenges effectively, it is essential to identify and understand the potential problems that may arise when biobased insulation material is being used. From several biobased materials, the properties and pros and cons are elaborated according to basic criteria. Hereafter, a score card (multicriteria analysis) is made which elaborates on all materials related to the criteria. Out of the score card, the three best materials are found which can be used as replacement of insulation in the traditional cavity wall. Lastly, from the three insulation materials it is worked out on how to exactly implement these insulation materials in the cavity wall.

2. Insulation matrices

A table has been created in which various insulation alternatives are analyzed.

		Thickness	Vapor	AW	Biobased	Embodied energie	Embodied corbon	Transport	Lifetime	Weight	Health	Transformability	Delivery	Storability	Cost	Final score	
Metisse	Rolls/panels	1	1	1	6	5	6	3	8	5	5	3	5	2	2	50	1
Cotton		1	1	1	10	1	0	3	10	5	5	5	5	0	4	48	2
Glasswool	Rolls	1	1	1	0	1	0	5	5	5	2	5	3	5	10	41	3
Recycled PET	Rolls	0	1	1	6	1	6	1	5	5	5	5	5	2	0	41	3
Wood fibre	Panels	1	1	1	10	0	6	1	10	0	5	3	3	2	0	40	4
Reeds	Panels	0	1	1	10	0	10	1	0	0	5	5	3	5	0	39	5
Cellulose	Granules	1	1	1	10	3	0	0	5	1	5	3	5	5	2	39	5
Flax	Panels	1	1	1	10	0	0	5	5	1	5	5	3	2	0	36	6
Strawbale		0	1	1 1	0	0	10	0	10	0	5	0	5	5	0	35	7
Expended clay	Aggregate	0	1	1	10			0	5	0	5	0	5	5	4	34	8
PIR	Panels	1	1		1 0	0	0	5	5	5	5	3	3	5	2	33	9
NIM	Panels	1	1	1	6	3		0	10	0	5	5	0	2	0	31	10
Hemp		0	1	1 1	0	6	5	1	0	3	5	0	5	2	2	29	11
Sheepwool	Rolls	1	1	1 1	0	3	0	0	5	5	5	3	5	2	0	28	12
Cork	Panels	1	1	1 1	0	0	0	0	10	0	5	3	3	5	0	26	13
VIP	Panels	1	1	1	6	0	6	1	5	3	5	0	0	0	0	26	13
Aerogels	Panels	1	1		1 0	0	0	0	5	0	5	5	3	5	0	23	14

Figure 3 overview of pros and cons for insulation

2.2. Material analysis

Glass wool is applied in the masonry cavity walls of the apartments. The lower ca. 80cm at the ground floor is limiting the thickness of the insulation material to 170mm, thus requires a lambda value of 0,037 as to reach $R! \geq 4{,}7\ m^2K/W$. The embodied carbon value of 6 kg CO2 per m2 is calculated to 34,50 $kg\ CO2/m3$. The lifetime of glass wool is indicated as 50 years.

- PIR (Polyurethane)

PIR is applied in the side façades being neighboured by other buildings. Here a maximum insulation thickness of 95mm is possible while $R! \geq 4{,}7\ m^2K/W$. PIR is a good solution for the high lambda value that it entails. The embodied energy and carbon rate are around 107 MJ/kg and 23,5 kg C02/m3. The latter is calculated based on the density ($5{,}9 * 30 = 177\ \ kg\ \ CO2/m3$) and has a 50 year lifetime.

- Wood Fibre

Wood fibre has a thickness of 180 mm was chosen to reach the necessary lambda value of $Rd \geq 4{,}7m(K/W$. It is highly efficient, healthy to process by not emitting any dust and being usable in a variety of ways; cavities of external walls included. The price per m2 is shown as 46,11 €. The vapour fusion resistance and absorbance counts to ≤ 2,0 km/m2 which undermine the product's moisture regulating ability and vapor permeability. Comparative analysis of building insulation material properties and performance' from 2020 is used to get data about the embodied energy (20,3 Mj/kg) and embodied carbon (0,124 kg CO2 eq/m3)

- Cork

Cork is a natural material which is being harvested from oak trees' The information about the pricing is taken from the Dutch website groenebouwmaterialien.nl, and compared to other alternatives, cork turns out to be rather expensive with a cost of 134,34€ per m2

- Cellulose

Cellulose as a material is obtained from newspapers and enhanced with additives, such as minerals, to improve fire safety and durability. During the processing, the newspapers are roughly shredded and then transformed into fine, flexible cellulose fibers at a fiber mill. The final product is carefully packed into bags and placed on pallets for storage or transportation. For cellulose, the product THERMOFLOC from the equally named Austrian firm was selected.

- Straw bale

A straw bale has a thickness of 260 mm rising up to 1.200 mm. For straw, the insulation layer must be enclosed to not lose any of the material and to protect it from climate related influences. Embodied energy and carbon of building insulating materials' that straw bale's has a negative carbon emission of minus 7 and is environmental friendly. The strawbale can completely be returned to the ecological cycle of nature.

- Cotton Pavatextile

For cotton, the product 'Pavatextiel' with a thickness of 180mm was chosen and has a thermally and acoustically insulating board made primarily from cotton fiber (85%) sourced from recycled textiles such as jeans and velvet, along with a blend of polyester fiber (15%). The cotton fiber utilized in this product demonstrates hygroscopic properties and has undergone treatment to enhance its resistance against bacteria, fungi, and fire, effectively preventing mites and mold. The products PAVATEXTIL and Métisse share values partially identical and similar. The only big difference is visible in the embodied energy/carbon values where Métisse is clearly posing as a more sustainable material with a lifetime of 75 years.

- Hemp

Hempflax has a CO2 negative impact which is almost in accordance with the values given by Kumar et al.'s research (0.14 kg CO2 eq/m3) (Kumar et al., 2020). HEMPFLAX is being produced in The Netherlands, Germany and Romania. According to the information given by the online shop Isolatieshop.nl, the product can be delivered in under a week (Isolatieshop, n.d.).

- Sheep wool

Sheep wool itself is nature-based sourced twice a year from sheep. The price is listed by the online website grounebouwmaterialien.de as 43,07 € per m2 (2023). A density of 20 kg/m³ makes the product very lightweight compared to other alternatives in the building industry. Most of the data can be found on their product sheet and considering the ecological parameters, the embodied energy for this product amounts to 23,44 MJ/kg and the embodied carbon is stated as low as 0,83 kg CO2-equiv./kg. As for fire protection, sheep wool takes twice as long as wood fibre.

- Flax

Flax is a biobased insulation alternative that originates from flax plants. Flax is an organic material that has no specific health concerns. It is easily cuttable with a specific knife and can be delivered within 2 weeks. The panels are made from torn fibres from the threated stalks and are hold together through a binding agent (Duijve, 2012). Only Kumar et al. give a number on the embodied carbon, which is calculated to kg CO2/m3 as follows: $20 * 49{,}33 * 0{,}179 = 176{,}22\ kg\ CO2/m2$ (Kumar et al., 2020).

- Reeds

The reeds panel is a perfect biobased insulation alternative. With rather limited workforce, solely binding reed stems together, high insulation rates are reached. These mostly result from the still-standing air in the stalks. The material of comparison is the Ecomat reeds panel (Ecomat, n.d.). The vapor resistance varies between 1 and 2 and the alpha-w value varies between 0.54 and 0.8 (Kumar et al, 2020). The embodied energy are 37 MJ/kg and embodied carbon of 0 kg/m2. The prices are €10,70 per m2 of 20mm thickness. A thickness of ca. 250mm is required.

- Aerogels

RS Pro is the producer of aerogel blankets, whereas the granules by Aerogel uk ltd are most efficient for cavity walls. The granules reach lambda values up to 0,012 values but release particular matter making them unfeasible for this project. Aerogel indicates a vapor fusion resistance of 7. Finally, the alpha-w is ranging between 0,54 nd 0,78. Embodied energies are given by Kumer at al. (2020) at 53,9 MJ/kg. The embodied carbon is recalculated to $4{,}3 * 150 * 0{,}085 = 54{,}56 \quad kg \quad CO2 \quad eq/m2$ with 150 being the density of granules in kg/m3. The lifetime for aerogel is specified by 50 years. The prices are €90 per m2.

- Vacuum isolated panels

Kingspan and Reticel are producers of vacuum isolated panels. The panels of Kingspan are made in width of 20 to 50 millimetres. The lambda value of Kingspan and Reticel are respectively 0.007 and 0.006 W/mk. This is a rather high lambda value and with this only a thickness of 33 millimetres of the panels would be necessary. The vapor fusion resistance of vacuum insulated panels is according to Reticel between 50 and 100. The alpha w value is 0.35 and the fire safety is E (Reticel 2017). The embodied energy is between 149 – 226 MJ/kg. The lifetime of these panels is about 50 years.

- Nano insulation material

Nanoporous insulation is a relative new insulation material and has a very low lambda value, as it is between 0.021 to 0.040 W/mk. The value of the insulation has to be only 100 millimetres. The vapor fusion resistance is 5.0 and the acoustic w – value is between 0.2 and 16. The embodied energie is between 1.4 and 2.685 MJ/kg. The costs of nano insulation material is nowadays equal to 280 euros per square meter.

- Recycled polyethylene terephthalate

Recycled polyethylene terephthalate (or in short PET) (in Dutch: Polyesterwol) is insulation material made out of recycled soft drink bottles. This insulation is also often used in acoustic isolation as it has good acoustic insulation. One producer in the Netherlands is EASYpol. The lambda value of recycled pet is between 0.034 and 0.043 W/mk. The thickness of the insulation has to be 188 millimetres. The vapor fusion resistance is equal to 5 and the acoustic w value is in between 0.2 and 0.8. The embodied energy produced to manufacture is equivalent to 43.22 MJ/kg. The price for the recycled pets are about 220 euro per square meter.

- Textile Métisse

Métisse insulation refers recycled fibres from textiles. Métisse can be bought in the Netherlands by multiple suppliers. Suppliers are for example InnoTherm/Pavatextil and VKR isolation. The lambda value according to the supplier for Métisse is 0.039 W/mk, which means that the required thickness of the insulation should be around 180 millimetres. The vapour fusion resistance and the acoustic w- value are 2.2 and 0.5-0.9 respectively. When the insulation is placed behind a facing, then the fire rating is B. Métisse is available in rolls as in panels. The available thickness varies between 50 and 200 millimetres. The embodied energy is 9.82 MJ/kg. The costs of Métisse is per square meter to achieve the desired Rc-value of 4.7 is 22.82 euro per square meters.

- Expended clay

Expended clay insulation refers to a type of thermal insulation material made from clay aggregate. It is derived from natural clay. It is often used as floor insulation for example. The supplier of expended clay in the Netherlands is Argex. The lambda value of expended clay is 0.09 W/mk (Laterlite, 2023). The thickness of the insulation would therefore be 423 millimetres. This is not achievable and in combination with that aggregate can't be properly installed into the cavity wall, makes that expended clay isn't further researched.

- Foam Glass

Foam glass is made from recycled glass that is crushed and mixed with a foaming agent. The mixture is heated, which results in a porous and lightweight structure. This structure has closed cells that trap air or other insulation. Foam glass is also often used to isolate pipes and such. The lambda value of the material is 0.058. The insulation thickness to achieve a Rc – value of 4.7 would then be 273 millimetres. The water fusion resistance and fire safety is unlimited and A1 respectively according to the supplier. The embodied energy is in producing foam glass is 54 MJ/kg. It is expected, according to the supplier that the foamglass isolation lifetime is equal to that of the building. The cost per square meters would then come out of more than 1400 euro per square meter.

- YBS Superquilt

YBS Superquilt is a multilayer reflecting aluminium insulation blanket. YBS is the manufacturer of this isolation material. The lambda value of YBS Superquilt is equal to 0.026 W/mk. This means that the YBS Superquilt insulation would need to be 122 millimetres thick. According to the supplier the vapor fusion resistance is equal to 75.000 if there aren't any seams in the insulation. However in construction there are always seams, then the vapor fusion factor is equal to 1700. For fire safety the resistance is equal to A1. The embodied energy is equal to 57 MJ/kg. YBS Superquilt is easily buyable in all kind of shops in the Netherlands for example in the Gamma or Hornbach. The costs of YBS Superquilt is equal to 19.59 euro per square metre.

- Mycelium

Mycelium isolation is isolation made from the root structure of fungi, called mycelium. This consists out of a network of fine, thread like structures. To produce isolation, the mycelium s mixed with straw or hemp. By doing so the mycelium spores grow. Mycelium is very much still a research topic and therefore it is not yet fully established in the Dutch market. At the moment, mycelium isolation is not buyable in large quantities in the Netherlands. The lambda value of mycelium is between 0.04 and 0.08

2.3. Translating characteristics into scores

For this project, we are looking for alternative solutions for finding insulation based on glass wool. In addition, we are looking for affordable insulation with an Rc value of 4,7. The maximum thickness is around 170 mm. In addition, this insulation must also have a vapor diffusion resistance, be affordable and use less energy. It would also be good to recycle insulation materials and, where necessary, extract CO_2 from the atmosphere. The prioritized categories based on customer preferences are "Bio-Based", "Embodied Carbon" and "Costs". The 2 alternatives that will suffice are sheep's wool insulation and YBS SuperQuil. However, sheep wool is a completely bio-based alternative to glass wool. While it still scores lower overall than glass wool at 38 instead of 41, it is the only risk-free viable alternative for this project. However, this risk-free alternative costs more than 5x the price of glass wool (€43.07). With the help of this change in the binary number, the first material that scores higher than glass wool in general is found. This material is Pavatextil with 48 points, compared to the 41 of glass wool. It is completely biobased, has a long lifespan and, at €19.16, is half the price of sheep's wool. The material is Métisse has a score of 50. This means that Métisse scores highest overall in this scenario. It is partially biobased, has low carbon and energy embodiment, and has a long lifespan. However, Métisse, with a cost of €22.82 per m2, is more expensive than cotton insulation. In order to be able to compare the 3 alternative materials, exploitation calculations and construction methods are made for all materials. The aspect of delivery on site in the construction methodology encompasses all materials and is therefore worked out first. Subsequently, the construction methodology and the exploitation calculations are worked out. In this chapter, the implications of the 3 material alternatives for short-term delivery requirements, the storage measures to be taken both during storage and after construction, the construction methodology and the characteristics in the construction of the material are discussed in more detail, all in the specific scope of the Sint Catharinastraat project.

- Sheep's wool. Due to the low density of sheep's wool (18 kg/m3 - ISOLENA sheep's wool) compared to other insulation materials, it is easy to carry on site. The material is supplied pre-cut in appropriate sizes in the form of rollers, and if a processing is required, sheep's wool can be manually torn out widthwise with bare hands or with an Isolena cutting device (Figure 24). Since the material does not release dust, it is easy to handle and there are no health risks that require the use of protective clothing. According to the manufacturer, a truss/metal profile structure is required as a frame in which the rollers are fastened to the sides or to the rear planking of the structure by means of staples (Figure 24). The rollers must be installed from bottom to top (ISOLENA, n.d.). The ISOLENA sheep's wool products are all plasma ion treated to provide protection against all kinds of wool pests. This method allows the material to be stored indefinitely, improving its durability (ISOLENA, n.d.). For optimal interior insulation, it is recommended to install ISOLENA sheep's wool near the interior. This can be achieved in a variety of ways, such as incorporating it into the installation levels, interior walls, or suspended ceilings. Another effective approach is to place it in the (biobased) vapour barrier in the roof structure or to integrate it into the acoustic levels (ISOLENA, n.d.).

- Cotton Pavatextil The insulation material Pavatextil P is similar to Métisse, but scores better on the restrictive noise reduction characteristic and requires a vapour barrier. The production site is located in Grobbendonk (Belgium), east of Antwerp (SOPREMA, 2020). The products are delivered by large trucks, which is a special concern regarding the small turning cycles near the site (SOPREMA, n.d.) On site, the pallets must be kept dry and out of the sun. At the same time, storing the pallets is explicitly not an option (Soprema, n.d.). This leads to complexities on the site where no sheltered storage is accommodated. In construction, the cotton panels can be easily handled and transformed on site. However, it should be borne in mind that a specific vapour barrier is required to prevent condensation of water in the cavity wall, which can damage the insulation material (SOPREMA, n.d.). The bio-based SOPRAVAP KRAFT vapour barrier could act as a perfect alternative. In addition, the construction process for Pavatextil only specifies its use in framework walls, such as metal stud, while its use in cavity walls also seems plausible. It requires additional fasteners, the same as in Métisse, shown in Figure 25 (SOPREMA, n.d.). Finally, Pavatextil contains a higher proportion of (waste) textiles (i.e. 85%), which makes it even more likely to be refurbished or recycled after the product's lifespan (SOPREMA, n.d.)

- Textiles Métisse. The Métisse insulation is delivered to the construction site by truck. There are several dealers in the Netherlands, the delivery time is less than a week when ordering. According to the supplier VKR insulation where possible, the trucks will be fully loaded. Métisse's depot in the Netherlands is located in Tilburg (VKR Insulation, 2023). Transport to the construction site is within 50 kilometres to the construction site in Eindhoven. On the construction site, the material will most likely need to be stored in a dry place. On the construction site, the Métisse can be easily cut and shaped into the right shape with a Métisse insulation cutter. This is a sharp and large knife to easily cut through the Métisse. However, it is likely that other sharp objects also do the work of cutting material. Because Métisse has a high rigidity, the Métisse insulation can be attached to the inner wing of the façade with light nails (VKR Insulation, 2023). No other construction methods are required for Métisse. During construction, no harmful particles are released on the skin. Métisse can be used without gloves. In addition, when Métisse is damaged (pressed, dented), the Métisse will return to its original thickness after about 1 hour (Green Building Materials, 2023). However, please note that 180mm does not require a prefabricated Métisse thickness, so the figure requires 26. Nail to connect the insulation to the inner application of 2 materials of 100 and 80 mm. This has consequences for the construction process. But according to the supplier, there is no need for a vaper barrier (VKR Insulation, 2023) After construction, the material does not require much maintenance. The lifespan of the product is 75 years. That is longer than the lifespan of regular buildings. After its lifespan, during demolition, the Métisse must be removed by hand. After it is removed, it is transported to the waste disposal site. Although Métisse can be refurbished/recycled to reuse it in a cavity wall, as of today, the supplier does not recycle Métisse. Today, 95% of the Métisse is taken to an incinerator where it is burned and electricity is made (VKR Insulation, 2023). However, this may change in the future. For the three best alternatives, sheep's wool, Métissse and Pavatextil, various calculations are carried out to put the material in perspective of its full life cycle. The operating calculation can be divided into two categories, namely energy calculations and cost calculations. To make the comparison more useful, an additional variant with sheep's wool is added, but with a greater thickness that reaches the boundary of the cavity. Since the development is for a social housing corporation, the cost plays an important role in the final choice of insulation material. As can be seen in appendix 6.1, there are large price differences between the different insulation materials, ranging from € 8.29/m2 for glass wool to € 53.84 for the 180 mm thick sheep's wool. Overall, glass wool is still unrivalled as an insulation material in terms of cost, and sheep's wool is the least favorable option among the selected alternatives in terms of cost, but performs better at the thermal insulation rates. The best bio-based alternative in this comparison is the Pavatextile cotton insulation.

Operaional systainablilty: the missing components in the sustainability calculations

As a counterpart to the costs, there is also the sustainability factor, because that is the reason for the research to find a more sustainable alternative to the glass wool insulation. For these two comparisons are made, one based on the embodied energy and one based on the embodied carbon, to put it in perspective. First, the total embodied energy of the insulation material is calculated in kWh and then compared to the annual energy savings. This is plotted in years to visualize when the embodied energy of the material is offset over time. Figure 34 visualizes this. It shows that all the materials are close to each other, except for Métisse. Glass wool is not even the material with the highest embodied energy. In general, the differences are small, and in the scope of the whole construction, the results are not significant. Within this figure, it becomes clear that cotton delivers the best CO_2 reduction per euro with about 80 grams of CO_2 savings per euro invested.

4. Recommendation

All in all, a very wide range of materials have been compared on both limiting and informative characteristics with respect to performance, construction method, durability and finances. The choice of materials takes a serious step outside the project scope by implementing both bio-based and state-of-the-art materials. The feasible context of the current status and requirements in the Sint Catharinastraat project. As a result of this restrictive framework, sheep's wool, Pavatextil and Métisse have proven to be viable alternative insulation products. By way of extension, these have been evaluated in response to the delivery, construction and storage issues that have emerged in the context of the project. On-site delivery is complex, but not exceptional compared to other on-site material deliveries. Nevertheless, the sheep's wool has to be transported from Austria, it is investment-intensive and has a specific and complex construction. By advocating for sheep's wool, it achieves higher insulation performance. Both textile insulation materials come with more standardized delivery specifications, construction methods, and costs. To round out the comparison, the additional investment costs and higher insulation rates of sheep's wool are reflected in the operating costs and embodied energies of the materials. Firstly, the higher insulation potential of sheep's wool with a thickness of 180 mm does not pay for itself over a course of 30 years. Second, the extra embodied energy for the extra thickness is recouped over time, but in hard performance against Métisse that is produced at much less embodied energy rates. In conclusion, sheep's wool is seen as an extraordinary insulation alternative that is too complex to apply in this project, mainly based on cost, construction methodology and embodied energy. The Pavatextil and Métisse are quite similar, although Pavatextil is cheaper, can be constructed in one layer, and has higher sound absorption. Pavatextil is therefore given minimal preference, even though it performs worse in terms of fire resistance, has a higher embodied energy and needs an additional (biobased) vapor barrier. Note that the limiting factors of the Sint Catharinastraat project have major implications for the outcome of this research; The cavity is fully engineered on glass wool and very limited financial space is given, while fire safety and noise requirements have remained open. This leaves sheep's wool as an interesting alternative in other contexts. Secondly, the use of Métisse and Pavatextil requires a very precise construction method, as a cavity of 20 mm must be maintained in the construction. As a rule of thumb, 40 mm should be used in the drawings, whereas now only 25 mm remains. This is a specific risk when administering both Métissse and Pavatextil. Finally, note that the project will have a unique 'drawn triangular' façade. This creates extra-thick cavities where additional insulation material can be placed to increase thermal performance and where the size of the cavity is not a problem for Métisse and Pavatextil. However, the option to apply additional insulation has not been elaborated in this research scope.

5. References

[1] GroeneBouwMaterialen. (2023). Metisse. Retrieved from: GroeneBouwMaterialen: https://www.groenebouwmaterialen.nl/metisse-katoen-isolatie-prt-pak.html
[2] VKR Isolatie. (2023). Metisse circulair katoen isolatie. Retrieved from Metisse: https://www.ecobouwmaterialen.nl/wp-content/uploads/2015/06/Me%CC%81tisse-isolatie-totaaloverzicht.pdf
[3] Aerogel uk ltd. (n.d.). Aerogel Uk Ltd, Aerogel Panels, High Temperature Aerogel Panels. Aerogel UK panels.
[4] Amorim Cork Insulation (n.d.). TECHNICAL FEATURES 100% RECYCLABLE. Retrieved June 8, 2023, from https://www.amorimcorkinsulation.com/en/the-process/technical-features/
[5] Back to Earth. (2023). Thermal and Acoustic Flexible Wood Fiber Wool Insulation – SteicoFLEX. Retrieved from Back to Earth: Thermal and Acoustic Flexible Wood Fiber Wool Insulation – SteicoFLEX
[6] Building Green. (2023). Greensulate – A fungus-based insulation material that is grown rather than manufactured. Retrieved from BuildingGreen: https://www.buildinggreen.com/blog/greensulate---fungus-basedinsulation-material-that's-grown-rather-manufactured
[7] Clay sign. (n.d.). Interior insulation - Clay sign. Retrieves June 6, 2023, From

[8] https://www.claytec.de/nl/nl/Producten/binnenisolatie/rietplaten_pid297#:~:text=Bouwplaat%20uit used %20wire%2Dstitched%20reeds,years%20for%20simple%20inner insulations%20.
[9] Ecomat. (n.d.). Ecomat reed plate. Retrieved June 4, 2023, from https://ecomat.be/bestandenbank/ecomatrietplaat-21.pdf
[10]Foam Glass (2023). Retrieved from FoamGlass: https://www.foamglas.com/nl-nl
[11]Tool-wise. (2023). Spit Nails Insulation Fastener- 80mm 038550. Retrieved from Gereedschappelijk: https://www.gereedschappelijk.nl/spit-nagles-isolatie-bevestiging-80mm-038550.html
[12]Green Building Materials. (2023). Metisse. Retrieves From: Green Building Materials:
[13]https://www.groenebouwmaterialen.nl/metisse-katoen-isolatie-prt-pak.html
[14]GUTEX Holzfaserplattenwerk (n.d.). Gutex thermosafe-homogeneous®. Retrieved June 7, 2023, from https://gutexbenelux.eu/assortiment/producten/produkt/gutex-thermosafe-homogen/
[15]GUTEX Holzfaserplattenwerk. (n.d.). (rep.). Experience the GUTEX effect. Waldshut-Tiengen: GUTEX Holzfaserplattenwerk.
[16]Insulation - South Africa Polyester Insulation. Retrieves From 7 June 2023 From: https://insulation.org.za/polyester/
[17]Insulation shop (n.d.). Hempflax Thermo Hemp Combi Jute insulation board 1200x580x180mm Rd:4.62 3pl/pack (=2,09 m²). Revised June 8, 2023, as of https://www.isolatiemateriaal.nl/ecologische-isolatie/hennepisolatie/hempflax-thermo-hennep-combi-jute-isolatieplaat-1200x580x180mm-rd462-3plpak-209-m2
[18]Isolena Naturfaservliese GmbH (n.d.). Sheep's wool: a natural insulator. Of course, healthy insulation is possible lake. Retrieves From https://www.groenebouwsystemen.nl/wp-
[19]King's Span. (2022). What is the Euroclass system? | Kingspan NL. https://www.kingspan.com/gb/en/knowledgearticles/what-is-the-euroclass-system/
[20]Insulation expert, Polyester wool insulation: Environmentally friendly insulation with many advantages at a favorable price. Retrieved June 7, 2023 from: https://isoleren-expert.nl/isolatiemateriaal/polyesterwol/
[21]Knauf Insulation. (n.d.-a). Insulation for sound absorption and acoustics. Retrieved June 4, 2023, from https://www.knaufinsulation.nl/kenniscentrum/geluidsabsorptie
[22]Kumar, D., Alam, M., Zou, P. X., Sanjayan, J., & Memon, R. A. (2020). Comparative analysis of the properties and performance of building insulation materials. Renewable and Renewable Energy Assessments, 131, 110038.
[23]Laterlite. (2023). Laterlite Expanded Clay: Lightweight Insulating Strong Aggregate. Retrieved from Laterlite: https://www.laterlite.com/products/lightweight-aggregates/lightweight-expanded-clay-aggregatelwa/
[24]Vette J.F. & Böttger W.O.J., Properties of Mycelium-composite biobased insulation materials with local organic waste streams as substrate and after use for mushroom cultivation. Retrieved June 7, 2023 from: https://www.coebbe.nl/app/uploads/2020/02/ProductieMycelium.pdf
[25]VKR Insulation. (2023). Circular cotton insulation. Retrieved from VKR isolation: https://vrk-isolatie.nl/
[26]YBS Insulation. (2023). YBS Superquilt. Retrieves From YBS Superquilt: https://ybsinsulation.com/brands/superquilt/