# Using natural fibre insulators on green roofs: some considerations

*Kristian* Fabbri[1], *Fabrizio* Barbieri[1] and *Francesca* Merli[2*]

[1]DA, University of Bologna, 47521 Cesena, Italy
[2]CIRI Edilizia e Costruzioni, University of Bologna, 40128 Bologna, Italy

**Abstract.** This study focuses on the application of coconut fibre insulators, an insulating material rarely utilized in the Mediterranean context. Despite its undoubted thermal performance, some queries are related with of his thermo-hygrometric behavior. More precisely, during the use of coconut for covering building for realizing green roofs, which represent a technological solution often adopted in the case of sustainable buildings or nearly zero energy building. Green roofs represent a valid constructive solution with high thermal performances, adopted in existing and new buildings. This paper investigates the thermo-hygrometric behavior of the concrete and Cross Laminated Timbre slabs, insulated with coconut fibreboards (CF) such as an alternative synthetic insulator, referred to a series of different green roofs scenarios. The results show that coconut fibre insulations are equally comparable to natural and synthetic materials. Therefore, coconut fibre could represent a good chance for realization of green roof having high thermal performance and hygrothermal behavior in the same time. This material could be an alternative solution to the normal synthetic materials actually used, in a perspective of sustainable architecture.

## 1 Introduction

New construction and historical buildings have specific characteristics regarding energy performance behaviour and indoor quality. The latter includes a high level of thermal comfort especially without any specific heating system, also balancing costs and performance [1, 2] and high levels of sound insulation from external and internal noise and the evaluation of the sound propagation. Acoustic measurement could be utilized for emulating sound propagation of musical instruments as brasses and trumpets [3], including non-linearities [4] and the analysis of sound propagation is particularly relevant for offices, auditorium [5, 6] and theatres [7,8] for the perception of sound [9].
Regarding the new technologies to improve the energy performance of the building, a recent covering technology used in the construction of the roof system is the green roof. This technological solution ensures high insulation and good thermal phase displacement. In many applications, the insulation materials applied in the stratigraphy are synthetic (e.g. EPS, etc.) or natural (e.g. wood fibre, wool glass, mineral wool, etc.). Between the natural

[*] Corresponding author: francesca.merli8@unibo.it

fibres, several products use “exotic” natural materials such as corn cobs, sheep wool, etc.. This research regards the study of the coconut fibres that are natural fibres with tropical material.
The green roof solution was studied from several Authors in recent years, and the thermophysical properties and thermal behaviour of such insulators were analysed in different applications, considering buildings located in Europe, South America and in the Asian Countries, i.e. where the use of local materials is higher. The application and evaluation of green roofs and its thermal performance in summer regime, winter regime and during the year were presented in several papers. The dynamic properties of the roofs during the summer period were studied by Tang and Zheng [10] and others authors [11, 12], while He et al. [13] in their research showed the differences in temperature between the green building covering and the same roof but in absence of the vegetation. In other papers, several Authors studied the seasonal hygrothermal behaviour of green roof, considering different draining layers and characteristics of the roof, including thermophysical and hydraulic properties, like the papers of Vila et al [14] and Coma et al. [15]. Zirkelbach et al. [16] only in their research defined the hygrothermal parameters for certain layers of the roof, but most of the Authors considered the global thermal performances of the green roofs, without defining the thermal parameters for every single layer.
The research is focused on “exotic thermal insulation materials” that refers to materials of various origins different from the common material used for in-building insulation, such as bamboo fibres, wood fibres or paper from industrial wastes, date palm fibres, corn cob, ichu fibres, rice straw, etc. Several authors treated these materials that could be used in the building construction sector. For example, date palm fibres [17], corn cobs [18], natural ichu fibres [19], and rice straw [20]. In the latter example, the Authors in addition to the thermal data reported also the mechanical properties. Moreover, Nguyen et al. in their research studied insulation materials in bamboo fibres, inserted in boards with bio-glues [21] and bio-binder [22], determining hygrothermal and mechanical parameters.
Among all the natural insulation material, this paper focuses on the “coconut fibre” which is utilised for different purposes. It could be applied to boards without adding chemical binders or other natural fibre substances or applied to mixed boards having varying content coming from agricultural production wastes. Moreover, the coconut fibre could be added as a loose raw material introduced into building materials or aggregated to other substances used for different applications. As far as the research on boards with natural substances is related, Panyakaew and Fotios [23] studied the hygrothermal behaviour among CF boards and bagasse fibreboards (BF). Hirunlabh et al. [24] reported the thermophysical properties of CF boards and durian peel (DP) boards with chemical resins as additives. Khedari et al. [25] determined the same values testing mixed boards among CF and DP, calculating also hygrometric parameters.
The purpose of this research is to determine the hygrothermal behaviour of green roofs with CF boards in the climatic zone “E”.

## 2 Goals

The study is aimed to determine the thermo-hygrometric behaviour of green roofs equipped with coconut fiberboard insulation and to analyse the differences of the thermal performances with EPS boards, applied to a case study which considers two different types of structures: concrete slab floor (CLS) and Cross-Laminated Timber floor (CLT).

## 3 Methodology

Firstly, the reference scenarios for the simulations and relative thermophysical data of the materials were defined and subsequently, simulations were performed using Termolog Epix 10 software.

### 3.1 Scenarios

Two types of building structure were considered: Concrete CLS and Cross Laminated Timber (CLT, in Italian normally named as XLAM), with and without air gap (AG). Each structure had the same stratigraphy except for the insulation layer with different material and thickness. The simulated scenarios are reported in Table 1.

**Table 1.** Definition of the layer and thermophysical characteristics of the green roofs.

| Slab | Air gap | Scenarios | Description |
|---|---|---|---|
| CLS | Without air gap | CLS 0 | No Insulation |
| | | CLS 1 | Coconut fibre insulation Th:8 cm |
| | | CLS 2 | Coconut fibre insulation Th:12 cm |
| | | CLS 3 | Coconut fibre insulation Th:16 cm |
| | | CLAS 4 | EPS insulation Th:8 cm |
| | With air gap | CLS + AG 0 | No Insulation |
| | | CLS + AG 1 | Coconut fibre insulation Th:8 cm |
| | | CLS + AG 2 | Coconut fibre insulation Th:12 cm |
| | | CLS + AG 3 | Coconut fibre insulation Th:16 cm |
| | | CLS + AG 4 | EPS insulation Th:8 cm |
| CLT | Without air gap | CLT 0 | No Insulation |
| | | CLT 1 | Coconut fibre insulation Th:8 cm |
| | | CLT 2 | Coconut fibre insulation Th:12 cm |
| | | CLT 3 | Coconut fibre insulation Th:16 cm |
| | | CLT 4 | EPS insulation Th:8 cm |
| | With air gap | CLT + AG 0 | No Insulation |
| | | CLT + AG 1 | Coconut fibre insulation Th:8 cm |
| | | CLT + AG 2 | Coconut fibre insulation Th:12 cm |
| | | CLT + AG 3 | Coconut fibre insulation Th:16 cm |
| | | CLT + AG 4 | EPS insulation Th:8 cm |

The thermophysical data of building materials are derived from the standard UNI 10351 [26], whilst the opaque ones from the standard UNI 10355. The thermophysical data of structures in CLT and coconut fibre boards are derived from the data sheets and increased by 20% accordingly to the standard UNI 10351.

### 3.2 Thermophysical and hygrothermal simulation

The calculation of the thermophysical performances of the green roofs was carried out according to UNI EN ISO 6946 [27] for the thermal behaviour, ISO 13788 [28] for the hygrometric behaviour, and ISO 13786 [29] for the dynamic thermal behaviour. Calculations were carried out with Termolog Epix 10 [30] based on UNI 10349 for the climatic data of the zone "E", and the UNI 11235 [31], for the realization of scenarios. Moreover, some other aspects related with economic aspects of energy enhancements or related factors [32] as multiscale analysis [33], confidence intervals [34], parametric assessment [35] variaton of thermal conductivity [36] and other mechanical aspects [37] were considered but not reported in this paper.

## 4 Results and Discussion

### 4.1 Interstitial condensation

The interstitial condensation depends on the stratigraphy and, in our case, the only element which varies among the scenarios is the insulation thickness in coconut fibre or EPS. Fig.1 reports the relationship between insulation's permeability concerning that of the roof, and the internal moisture production rate (Gc). Interstitial condensation occurs in the roof with coconut fibre insulation CF(thickness from 12 to 16 cm), in absence of ventilation layer (CLS 2, 3 with values 0.013 Kg/m$^2$ and 0.022 Kg/m$^2$), and presence of this one (CLS + AG 2 and 3 with values 0.113 Kg/m$^2$ and 0.092 Kg/m$^2$). This is due to the high difference between the coefficient of vapour resistance (μ) of the various layers, related their thicknesses, causing condensation.

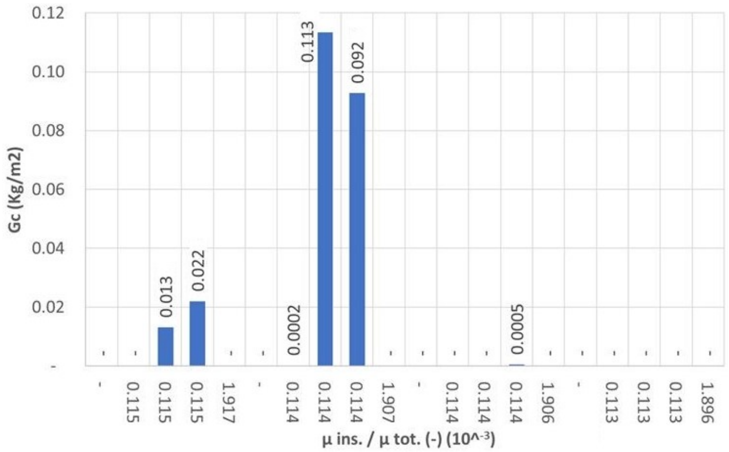


**Fig. 1.** Hygrometric behaviour of the scenarios compared to the incidence of the material and the amount of vapour accumulated monthly.

### 4.2 Thickness and transmittance

Another aspect is to evaluate whether there is a linear relationship between the stratigraphy's thickness of green roof and its transmittance U (W/m$^2$K). Fig.2 shows that there isn't linearity between thickness and transmittance.

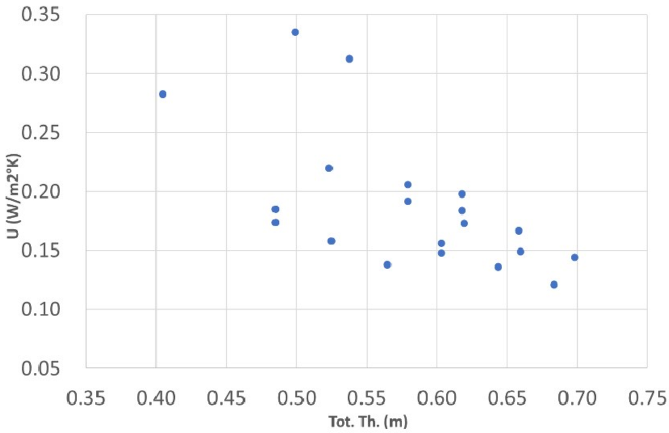


**Fig. 2.** Trend's variation of thermal transmittance (U) in steady-state, compared to the increase of the total thickness (Tot. Th.) of the green roof: no correlation between parameters.

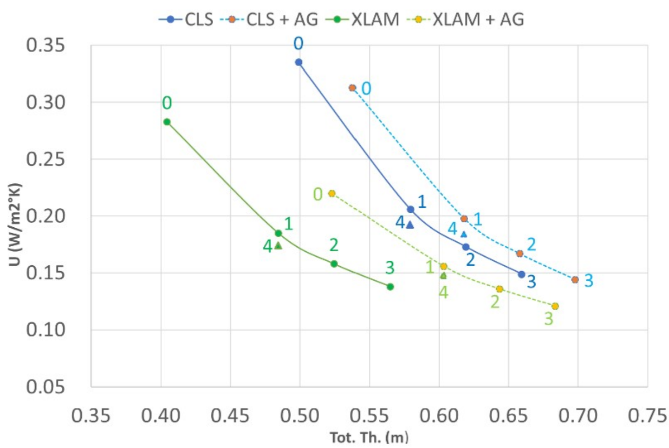


**Fig. 3.** Trend's variation of thermal transmittance (U) in steady-state, compared to the increase of the total thickness (Tot. Th.) of the green roof: correlation between parameters, thanks to a different bearing system.

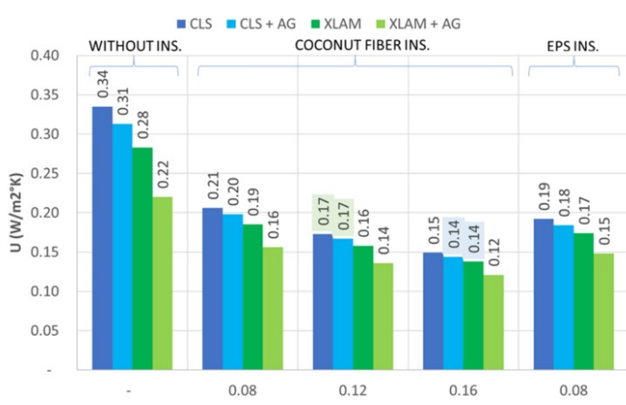


**Fig. 4.** Thermal behaviour in steady-state (U) of the green roofs, compared to the presence/absence of the insulating material in addition to its thickness (Ins. Th.).

This correspondence occurs when analysing each green roof's structure. Fig. 3 shows that a linear relationship is found only for roofs belonging to the same constructive typology and the same insulation material. Looking more in detail Fig. 4 regarding coconut fibre insulation, it is possible to see that considering the same insulation thickness (12 cm and 16 cm), we have identical thermal performances between roofs having different stratigraphy (highlighted values). Furthermore, we have negligible transmittance differences, (roughly 0.01 W/m$^2$K) when we analyse all the green roofs with and without insulation layer (the differences is roughly 0.03 W/m$^2$K).

### 4.3 Thermal behavior in a dynamic system

Analysing the relationship between thermal periodic transmittance (Y) and insulation's thermal conductivity ($\lambda_{ins}$) reported in Fig. 5, we found no significant differences between the performance of CF and EPS for all the roofs having the same thickness. Nevertheless, we found equal performances between CLS and CLT for roofs with and without the insulation layer.

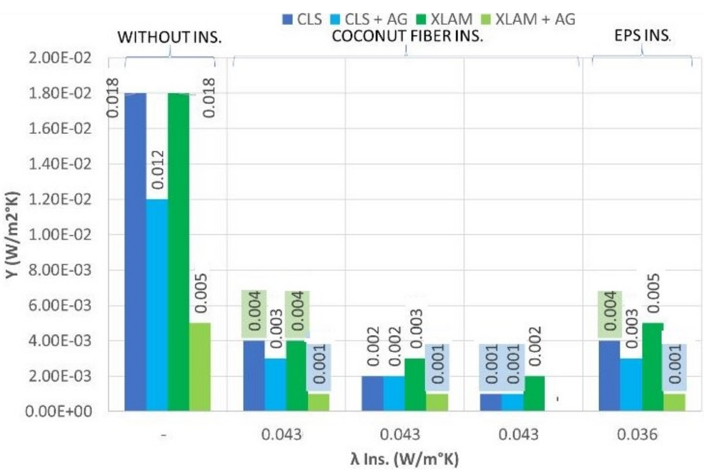


**Fig. 5.** Thermal behaviour in dynamic conditions (Y) of the green roofs, compared to the presence/absence of the insulating material in addition to its thermal conductivity ($\lambda_{ins}$).

From this parameter, we calculated the thermal phase shift time. Comparing CF and EPS 8 cm thickness, we obtained the main value of the difference between the two materials of about 1 hour and 20 minutes. We could state that this delay might depend on both thickness and the thermophysical characteristics of each layer of the roof.

## 5 Conclusion

This research was aimed to study the thermo-hygrometric behavior of the concrete and Cross-Laminated Timber (CLT) slabs, insulated with coconut fibreboards (CF). The results showed that CF and EPS reached the same thermo-hygrometric performance, as reported in scenario 3 (Fig. 5). This is an important result since CF represents a natural material whereas EPS is a synthetic one. Furthermore, the CF resulted in having a time shift 1 hour higher if compared to the synthetic insulator. However, there are some important constraints related to CF. First of all, CF is an "exotic" material, without any information (even not certified) about its thermo-hygrometric behaviour, and there is also another important component which is not considered in this work, which needs further and separate evaluation, i.e. the presence (or absence) of grass and other vegetal plants on the roof. So far, there is no specific and clear evaluation on this particular aspect and it deserves further and specific evaluation even by mean of experimental measuring campaign including in situ measurements, to determine its effect in energy behaviour and performance, including its potential effectiveness.

## Nomenclature

Gc Moisture production rate [kg/m$^2$]
$\mu$ Vapour resistance coefficient [-]
U transmittance [W/m$^2$K]
Y thermal periodic transmittance [W/m$^2$K]
$\lambda_{ins}$ insulation's thermal conductivity [W/mK]

## Acknowledgments

The work described in this paper was carried out within the project "Research for SEAP: a platform for municipalities taking part in the Covenant of Mayors", financed by Italian Government in the framework of PRIN 2015 and the project "SIPARIO – Il Suono: arte intangibile delle Performing Arts – Ricerca sui Teatri Italiani per l'Opera" POR FESR 2014-20 n. PG/2018/632038.

## References

1 L. Tronchin, M. Manfren, B. Nastasi, Renewable & sustainable energy reviews **95**, 341-353 (2018).

2 L. Tronchin, K. Fabbri, Energies **10**(10), 1621 (2017).

3 A. Farina, L. Tronchin, Acustica **86**, 737-745 (2000).

4 L. Tronchin, V.L. Coli, VL. AES J Audio Eng Soc **63**, 671-683 (2015).

5 A. Farina, L. Tronchin, Acta Acustica united with Acustica **99,** 118-125 (2013).

6 L. Tronchin, D.J. Knight, International Journal of Historical Archaeology **20**, 127-145 (2016).

7 L. Tronchin, F. Merli, M. Manfren, Applied Acoustics, **172**, 107598 (2021)

8 L. Tronchin, F. Merli, M. Dolci, Applied Acoustics, **172**, 107595 (2021)

9 R. Shimokura, L. Tronchin, A. Cocchi, Y. Soeta J. Sound Vib. **330**(14), 3526-3537 (2011).

10 M. Tang, X. Zheng, Appl. Energy. **242**, 1010–1021 (2019).

11 F. Lisi, G. Santi, F. Leccese, D. Testi, F. Cinelli, Acta Hortic. **1215**, 81-88 (2018).

12 C. Bibbiani, C. Gargari, C. A. Campiotti, G. Salvadori, F. Fantozzi, Innovative Biosystems Engineering for Sustainable Agriculture, Forestry and Food Production, Springer International Publishing, 169-177, (2020).

13 Y. He, H. Yu, A. Ozaki, N. Dong, S. Zheng, Energy Build. **148**, 142–154 (2017).

14 A. Vila, G. Pérez, C. Solé, A.I. Fernández, L.F. Cabeza, Build. Environ. **48**, 101–106 (2012).

15 J. Coma, G. Pérez, C. Solé, A. Castell, L.F. Cabeza, Renew. Energy. **85**, 1106–1115 (2016).

16 D. Zirkelbach, S.R. Mehra, K.P. Sedlbauer, H.M. Künzel, B. Stöckl, Energy Build. **145**, 79–91 (2017).

17 M.E. Ali, A. Alabdulkarem, Constr. Build. Mater. **138**, 276–284 (2017).

18 A. Paiva, S. Pereira, A. Sá, D. Cruz, H. Varum, J. Pinto, Energy Build. **45**, 274–279 (2012).

19 S. Charca, J. Noel, D. Andia, J. Flores, A. Guzman, C. Renteros, J. Tumialan, Energy Build. **108**, 55–60 (2015).

20 K. Wei, C. Lv, M. Chen, X. Zhou, Z. Dai, D. Shen, Energy Build. **87**, 116–122 (2015).

21 D.M. Nguyen, A.C. Grillet, T.M.H. Diep, C.N. Ha Thuc, M. Woloszyn, Constr. Build. Mater. **155**, 852–866 (2017).

22 D.M. Nguyen, A.C. Grillet, Q.B. Bui, T.M.H. Diep, M. Woloszyn, Constr. Build. Mater. **186**, 686–698 (2018).

23 Panyakaew, S. Fotios, Energy Build. **43**, 1732–1739 (2011).

24 J. Hirunlabh, J. Khedari, S. Charoenvai, Build. Environ. **38**, 435–441 (2003).

25 J. Khedari, N. Nankongnab, J. Hirunlabh, S. Teekasap, Build. Environ. **39**, 59–65 (2004).

26 UNI, UNI 10351 Building materials. Thermal conductivities and vapour permeabilities (Materiali da costruzione. Conduttività termica e permeabilità al vapore), (2010).

27 U.E. ISO, UNI EN ISO 6946 Buildings components and buildings elements_Thermal resistance and thermal transmittance_Calculation method (Componenti ed elementi per edilizia Resistenza termica e trasmittanza termica Metodo di calcolo), English. (2010).

28 ISO, ISO 13788 - INTERNATIONAL STANDARD Hygrothermal performance of building components and building temperature to avoid critical, (2012).

29 ISO, ISO 13786 - INTERNATIONAL STANDARD Thermal performance of building components - Dynamic thermal characteristics - calculation methods, 2–7 (2016).

30 Termolog Epix 10.pdf, (n.d.).

31 UNI, UNI 11235 - Criteria for design, execution, testing and maintenance of roof garden (Istruzioni per la progettazione, l'esecuzione, il controllo e la manutenzione di coperture a verde), 37 (2007).

32 L. Tronchin, M.C. Tommasino, K. Fabbri, International Journal of Sustainable Energy Planning and Management **3**, 49-62 (2014).

33 L. Tronchin, M. Manfren, L.C. Tagliabue, Sustainable Cities and Society **27**, 296-306 (2016).

34 L. Tronchin, K. Fabbri, Energy Policy **48**, 176-184 (2012).

35 L. Tronchin, M. Manfren, P.A. James, Energy **165**, 26-40 (2018).

36 U. Berardi, l. Tronchin, M. Manfren, N. Nastasi, Energies **11** (4) 872 (2018)

37 L. Tronchin, K. Fabbri, C. Bertolli, Energies **11** (8) 2123 (2018)