Optimization of the thermal properties of wood fibre-based insulating materials

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Performance bio-based building materials and Superior bio-friendly systems for enhanced wood durability
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1. *Wood-fibre-insulating-boards divided in two class*

✓ Rigid:

➔ Conventional wet process

- Bulk density 110-280 kg/m^3
- Lignin and hemicelluloses as a bonding agent
- High mechanical properties
- Maximum thickness of a single layer 10 mm *(high thicknesses obtained by gluing multiple layer)*

✓ Semi-rigid:

➔ Dry process derived from the nonwoven industry

- Bulk density < 50 kg/m^3
- Bonding agent needed thermoplastic
- Low mechanical properties *(bending under own weight)*
- Maximum thickness of a single layer 100 mm

➔ *Multifonctionnal materials*

➔ *Poised to **grow at a rate of 10% year-on-year** to 2020 on european market*

(Alcimed, 2012)

2. French ECOMATFIB project objectives (funding by ADEME):

✓ Optimize the properties of semi-rigid wood fibres-based insulating materials so that they become more competitive especially through the optimization of the manufacturing process by :

- *improving local raw materials selection (southwest of France)*
- *improving production methods*
- *reducing cost and environmental impacts*

➔ Key technical aspect is to improve R-value:
(twice as expensive as mineral wools at equivalent R)

thermal resistance $R\ [m^2 \cdot K \cdot W^{-1}] =$ *thickness* $[m]$ / *thermal conductivity* $\lambda\ [W \cdot K \cdot m^{-1}]$

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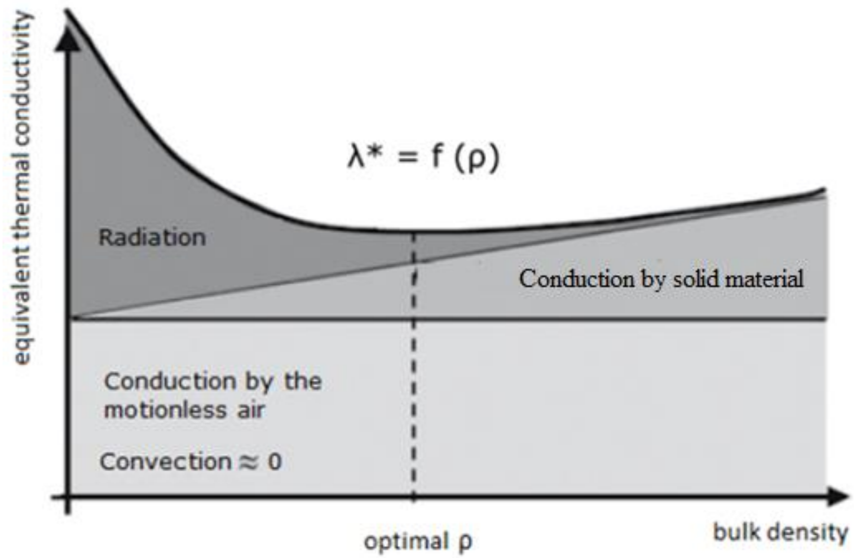
3. How minimizing thermal conductivity ?

- ✓ *By optimized organization of the complex entangled fibrous network:*



Influence of the bulk density on equivalent thermal conductivity of insulating materials (Coquard, 2012)

- ✓ *By assessing the impact of the raw material morphology and manufacturing settings on the internal structure and thermal conductivity*

1. Manufacturing process used for the design of semi-rigid wood fibre-based insulating materials

Maritime pine chips locally present in southwest of France

Defibering of wood chips into fibres and fibres bundles

pressurized 12" refiner from Andritz in FCBA Grenoble

Opening of raw materials and 3-D fibrous web formation

Cadette Airlaid machine from Laroche in I2M Talence

3-D fibrous batt consolidation

through hot-air oven from Strahm in I2M Talence

xyloforest Recherche & Innovation Forêt-Bois

2. Design of Experiments

Raw materials:

- ✓ *One local renewable resource* : maritime pine (PM)
- ✓ *One thermoplastic fibre* : polyolefin (S) 6 mm length and 20 µm diameter

Process settings:

- ✓ *Fibre production by adjusting gap between the two profiled discs of the defibrator*: 5 different populations of maritime pine fibres *labelled PM1 to PM5*
- ✓ *Fibre mat Compression ratio (CR) during pression and heating of the 3D fibrous networks (thickness formatting):* 3 density levels obtained for each blend PMiS (15 specimens)

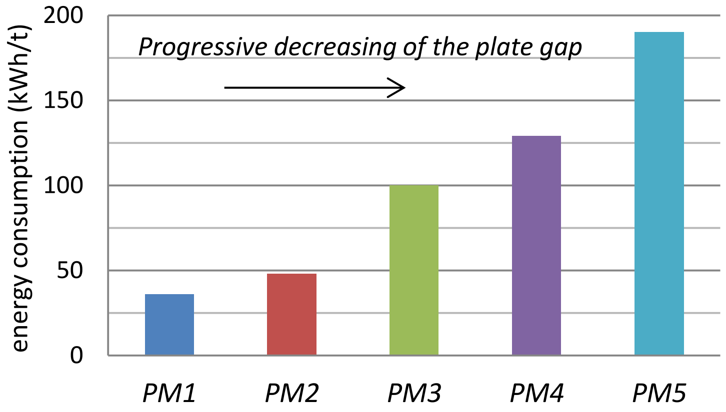
3. Characterization of raw materials by X-ray microtomography

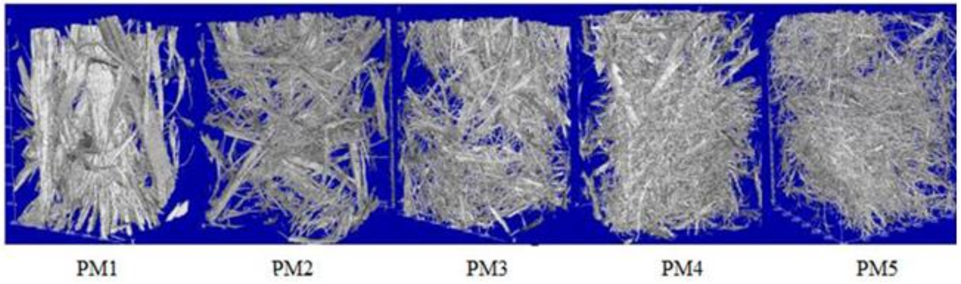
- ✓ Non-destructive imaging technique *(SkyScan 1174 microtomograph)*
  - X-ray projections
  - 3D reconstruction of X-ray projections
  - Morphological measurement on the virtual volume (digital picture)
- ✓ Observation / characterization of the size of wood fibres diameter and its distribution

4. Characterization of the thermal properties of the panels by the hot plate technique

- ✓ Indirect assessment of apparent thermal conductivity from measurements of effusivity and volumetric heat capacity *(Desprotherm device Epsilon Alcen)*
  - Specimens size: 100x100*e* (mm^3), with *e* the thickness
  - Specimens stabilized before measurement at 20°C/65%RH
  - *20°C/65%RH during all measurements*

1. Energy consumption during defibering and morphology of wood fibres





Respective energy consumption of wood fibres population and 3D volume rendering imaging of their population
(image resolution is 12.3 microns/voxel and the analysed volume is 8.6 x 8.6 x 12.3 mm^3)

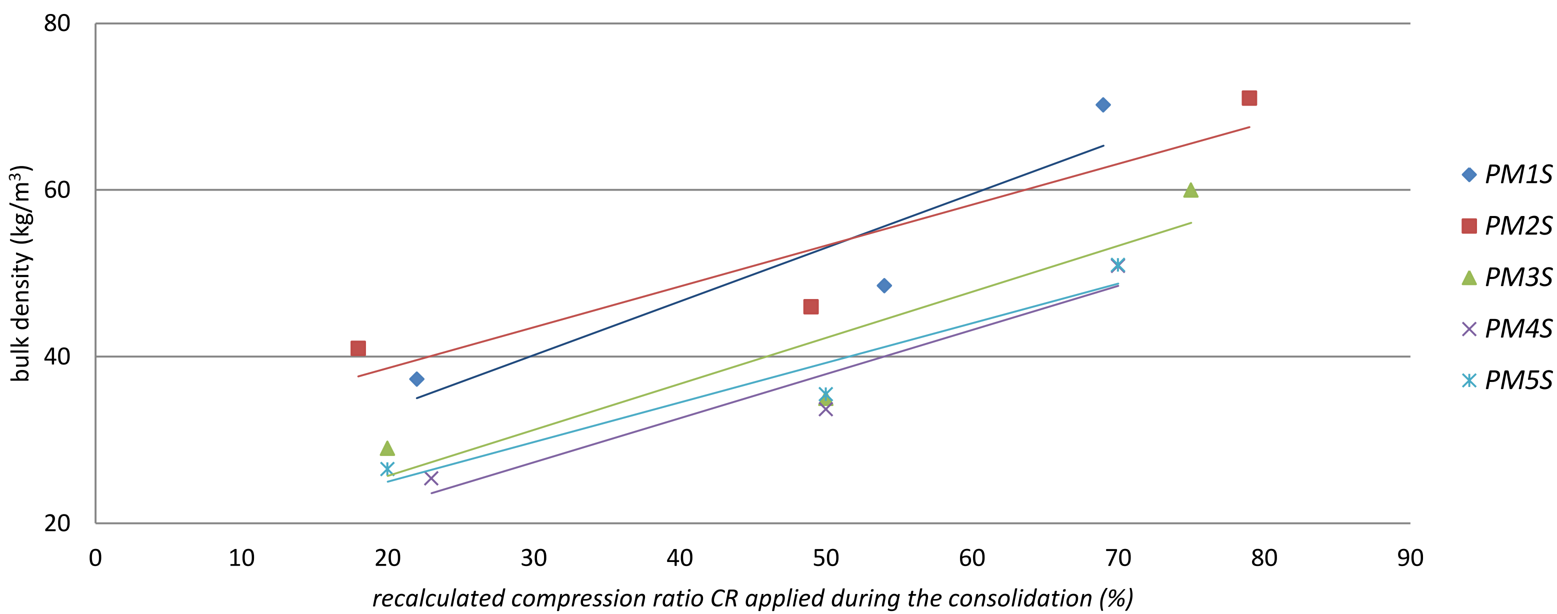
As expected, reducing plate gap from PM1 to PM5:

➔ *Increase energy consumption*

➔ *Decrease the dimension of the corresponding wood fibers*

- PM2 fibres population close to that used for current insulating materials
- PM5 fibres population close to that used for MDF

2. Variability of apparent bulk density of the 15 panels manufactured



Influence of the compression ratio of each blend during their consolidation on the mean bulk densities

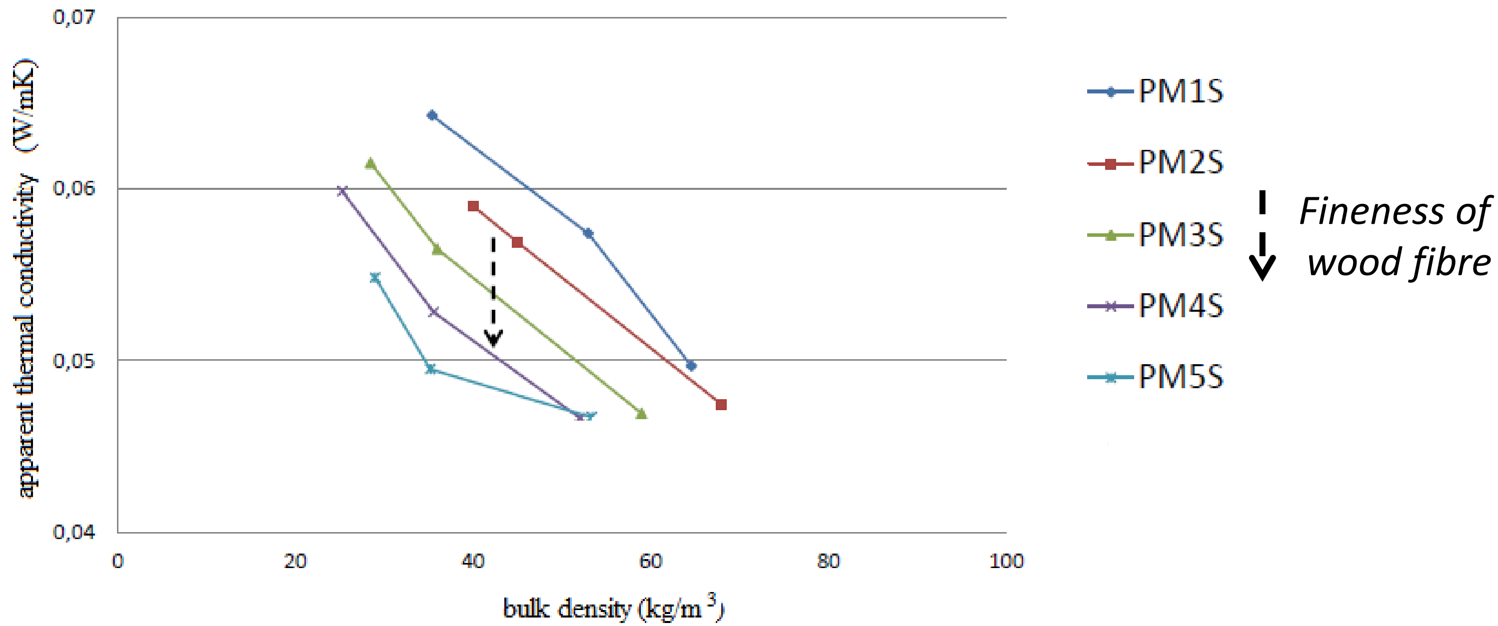
✓ Bulk densities ranging from 25 to 75 kg/m^3

➔ Highly porous materials (>90%) considering cell wall density of wood equal to 1 530 kg/m^3

➔ Manufacturing process suitable for design of fibrous networks made up of fine wood fibres

3. Experimental values of apparent thermal conductivities / bulk density

✓ moisture content at the equilibrium state 20°C/65%RH of wood fibreboards comprised between 10 and 11% by mass



Influence of bulk density of each blend on apparent thermal conductivities assessed by the hot plate method at 20°C/65%RH

Apparent thermal conductivities:

➔ well correlated with bulk densities

➔ also influenced by the degree of destructuration of maritime pine chips

4. Simulation modelling of apparent thermal conductivities / bulk density (1/3)

From a semi-empirical model proposed by *(Langlais et al., 2004):*

$$\lambda^*(\rho) = A + B\rho + \frac{C}{\rho}$$

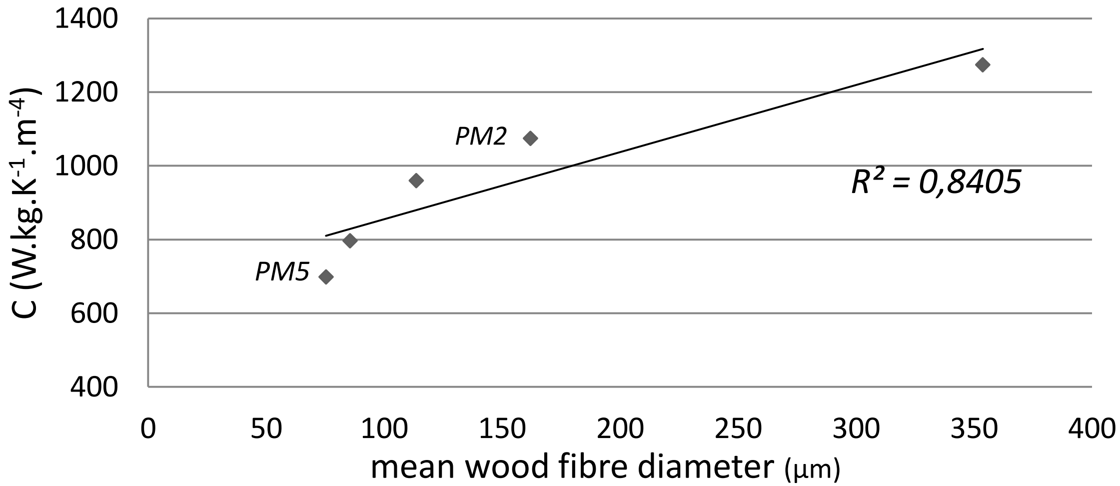
➔ *possible to simulate the development of the different modes of heat transfer inside fibrous insulating materials with regard to its density by considering:*

- *A* conduction in the air (equal to 26 mW/mK at 25°C)
- *Bρ* conduction in the solid matrix
- *C/ρ* radiation inside the fibrous network

➔ *B and C parameters can be estimated by the Levenberg-Marquardt method from experimental results λ*(ρ)*

4. Simulation modelling of apparent thermal conductivities / bulk density (2/3)

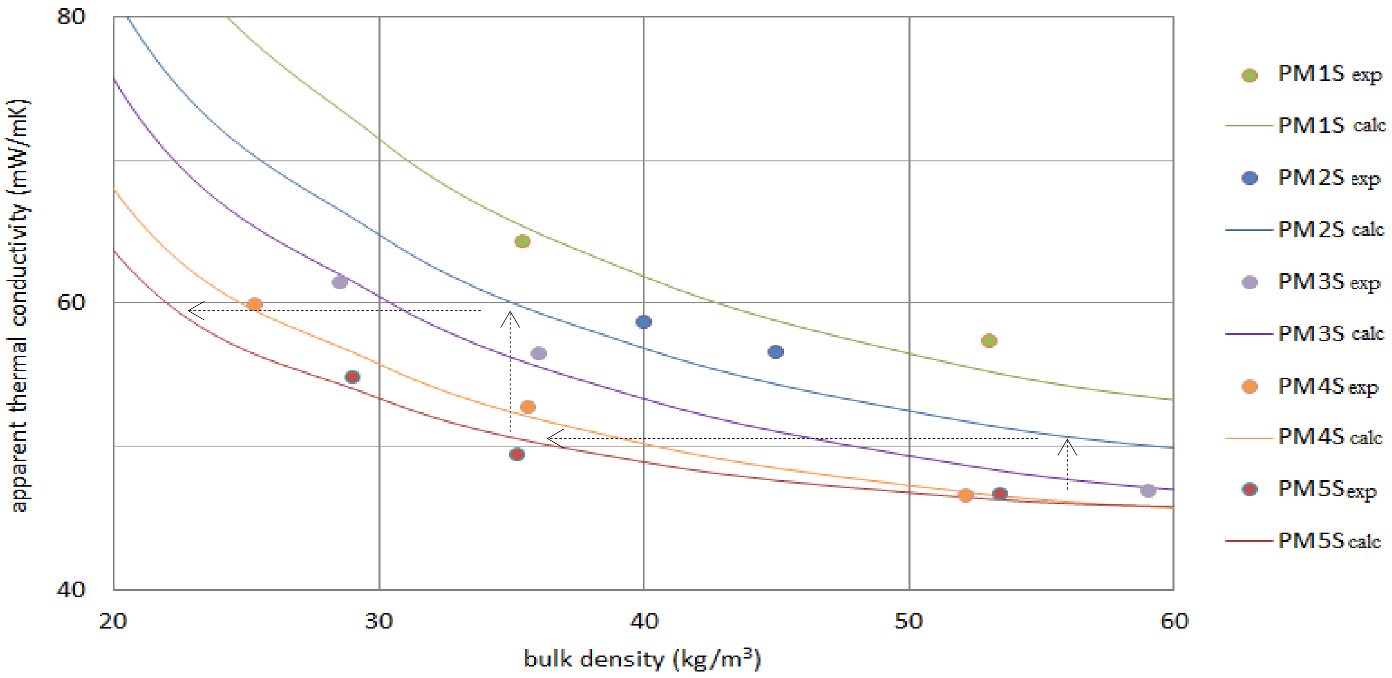
Influence of mean wood fibre diameter on C parameter value:



➔Finer fibres are better as soon as radiation contribution is no longer negligible and become preponderant in front of solid conduction

4. Simulation modelling of apparent thermal conductivities / bulk density (3/3)

Evolution of apparent thermal conductivities depending on the bulk density of the PMiS blends:
PMiSexp are experimental data and PMiScalc are the curves calculated using the semi-empirical model



➔ *Influence of fine fibres on apparent thermal conductivity is more and more important when bulk densities are very low*

- *Nonwoven process adapted to design wood fibres based materials:*
  - ✓ Highly porous (>95%)
  - ✓ Made up of fine elements (wood fibres used in MDF)

- *Apparent thermal conductivity optimization from:*
  - ✓ Raw materials morphology : lower when fineness increase
  - ✓ Bulk densities, adjusted via compression ratio during consolidation

- *Although finer fibres require more energy consumption to be produced, their use seems to be justified at low density where radiation is no longer negligible and become a more and more important contribution in apparent thermal conductivity*

Future works

- ✓ Semi-empirical model development considering moisture content influence
- ✓ Estimation of the moisture buffering values
- ✓ Estimation of the compressibility (thickness recovery after being compressed) interesting for transport and service-use
- ✓ New wood species and thermoplastic fibres will be investigated in the coming month
- ✓ Combined all data, with that obtained from the environmental and economic objectives

➔ Use a multi-objective optimization technique to find the best compromise that simultaneously satisfy these conflicting goals

Thank you for your attention!