Thermal insulating materials made up of poplar wood fibres

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1. Two process available for design wood-fibre-insulating-boards:

✓ *Conventional wet process: Rigid panels*

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


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✓ *Dry process: Semi-rigid panels*

(derived from the nonwoven industry)

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


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➔ *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)*

  ➔ ***Currently made up of maritime pine : what about poplar ?***

- *improving production methods*
- *reducing cost and environmental impacts*

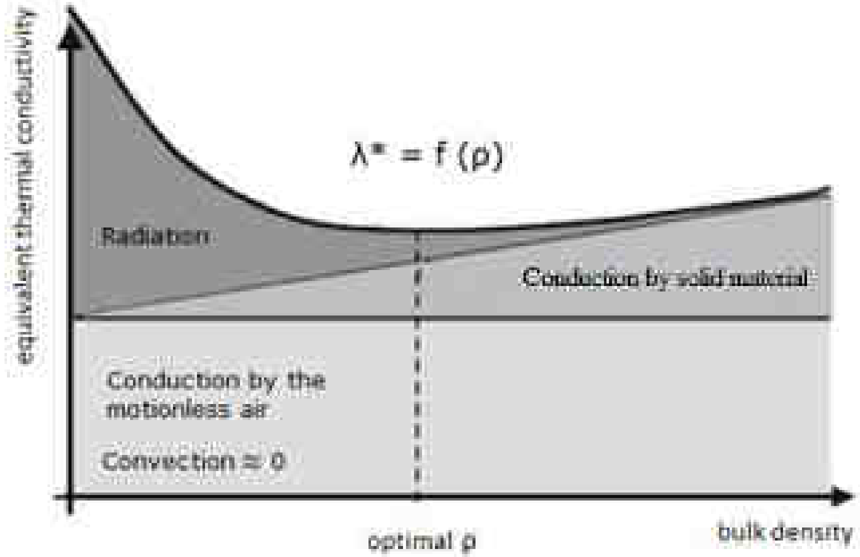
➔ Key technical aspect is to improve R-value:

(twice as expensive as mineral wools at equivalent R)

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

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 on the internal structure and thermal conductivity*

➔ *both the consequence of the manufacturing process*

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

Wood 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

2. Design of Experiments

Raw materials:

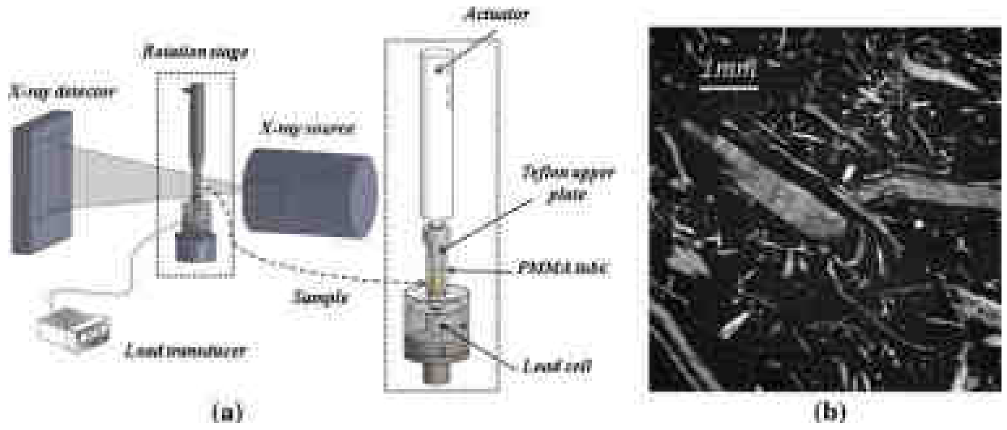
- ✓ *Two local renewable resources* : ***maritime pine (PM) and poplar (PR)***
- ✓ *One thermoplastic fibre* : polyolefin (S) 6 mm length and 20 µm diameter

Process settings:

- ✓ *Fibre production by adjusting gap between the two profiled discs of the defibrator*:
  - ➔ *a PM1 population* close to that currently used for insulating materials
  - ➔ *a PM2 population* close to that used for MDF
  - ➔ *a PR population* close to PM2
- ✓ *Fibre mat Compression ratio (CR) during pression and heating of the 3D fibrous networks (thickness formatting):*
  - ➔ 3 density levels obtained for each blend labelled *PM1S, PM2S and PRS*

3. Characterization of raw materials by:

a. X-ray microtomography for investigating size of fibres diameter and its distribution



a) In-situ setup in X-ray microtomography and b) 2D slice (Tran, 12)

- ✓ Non-destructive imaging technique *(SkyScan 1174 microtomograph)*
  - X-ray projections
  - 3D reconstruction of X-ray projections
  - Morphological measurement on the virtual volume (digital picture)

3. Characterization of raw materials by:

b. Bauer Mc Nett equipment for investigating size of fibres length and its distribution

Bauer McNett workbook with 4 tanks (FCBA Grenoble)

- ✓ 4 sieves 8/14/28/35 in cascade with openings accordingly 2.4;1.4;0.84 and 0.5 mm
  - 10 grams of dry matter introduced for each wood fibres population
- Weight of fibres retained by each sieve is converted to a fraction limited to the size of the sieve

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

- ✓ Indirect assessment of apparent thermal conductivity *λ*app* from measurements of effusivity *b* and volumetric heat capacity $\rho.\ C_p$ *(Desprotherm device of Epsilon Alcen)*

Device measurement of b

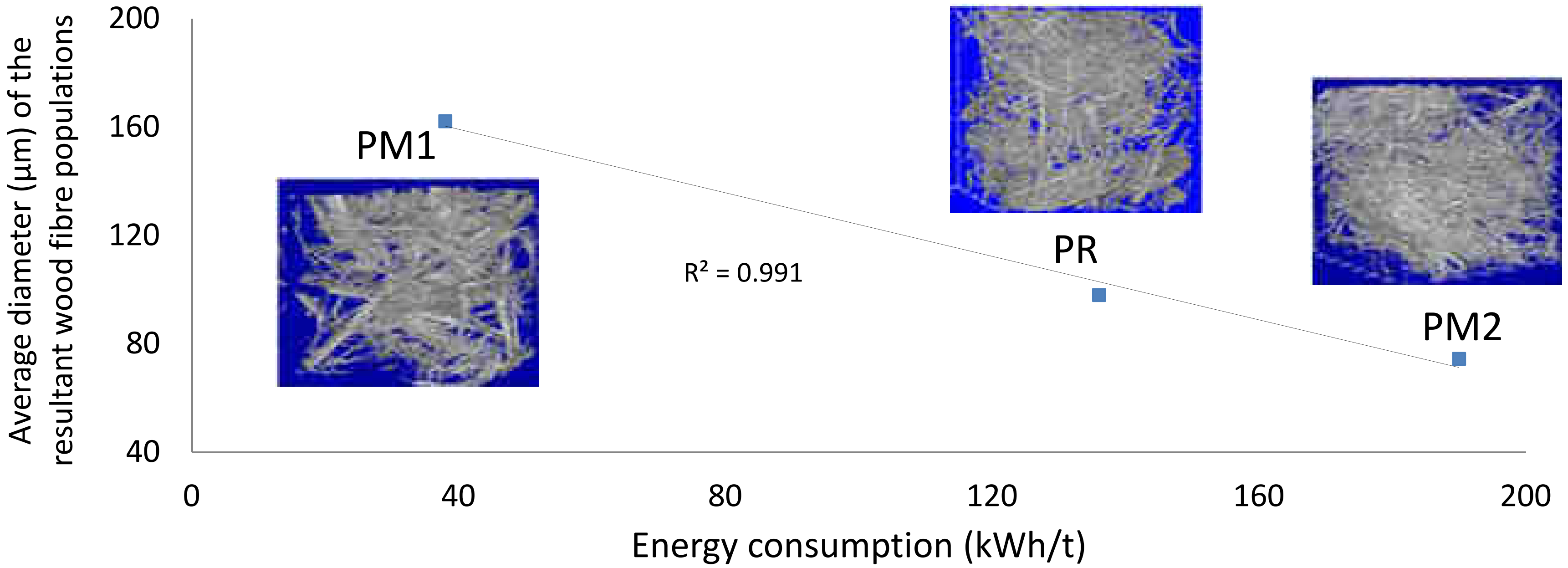
$$\boxed{\lambda^*_{app} = b^2 / \rho.\ C_p}$$

Device measurement of ρ.Cp

- Specimens size: 100 x 100 x *e* (mm^3), with *e* the thickness
- Specimens stabilized before measurement at 20°C/65%RH
- during all measurements: 20°C/65%RH

1. Energy consumption during defibering and morphology of wood fibres (1/2)

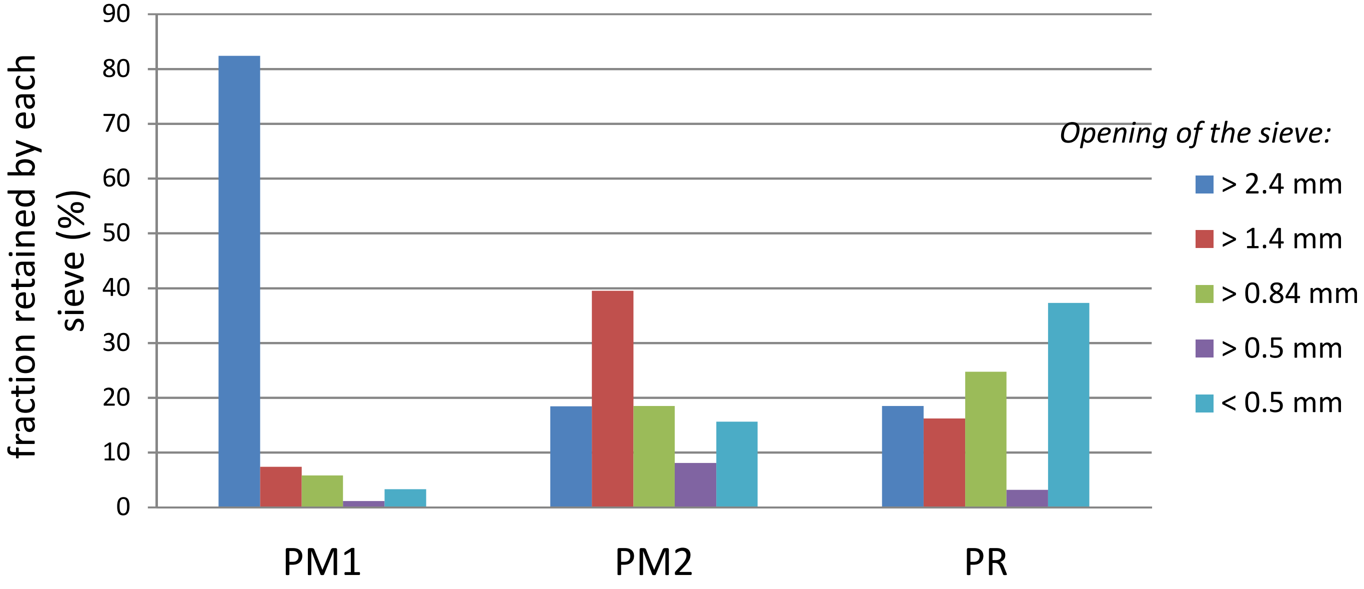
Influence of energy consumption on average diameter of the wood fibre populations:
(analysed on virtual volume of 8.6 x 8.6 x 12.3 mm^3 with a resolution of 12.3 microns/voxel
obtained by X-ray microtomography)



- ✓ *Increasing of energy consumption decreases the dimension of the corresponding wood fibers*

1. Energy consumption during defibering and morphology of wood fibres (2/2)

Bauer McNett fractions obtained for each wood fibres population:



✓ In agreement with their current use

➔ PM1 has a strongest rejection (opening >2.4mm)

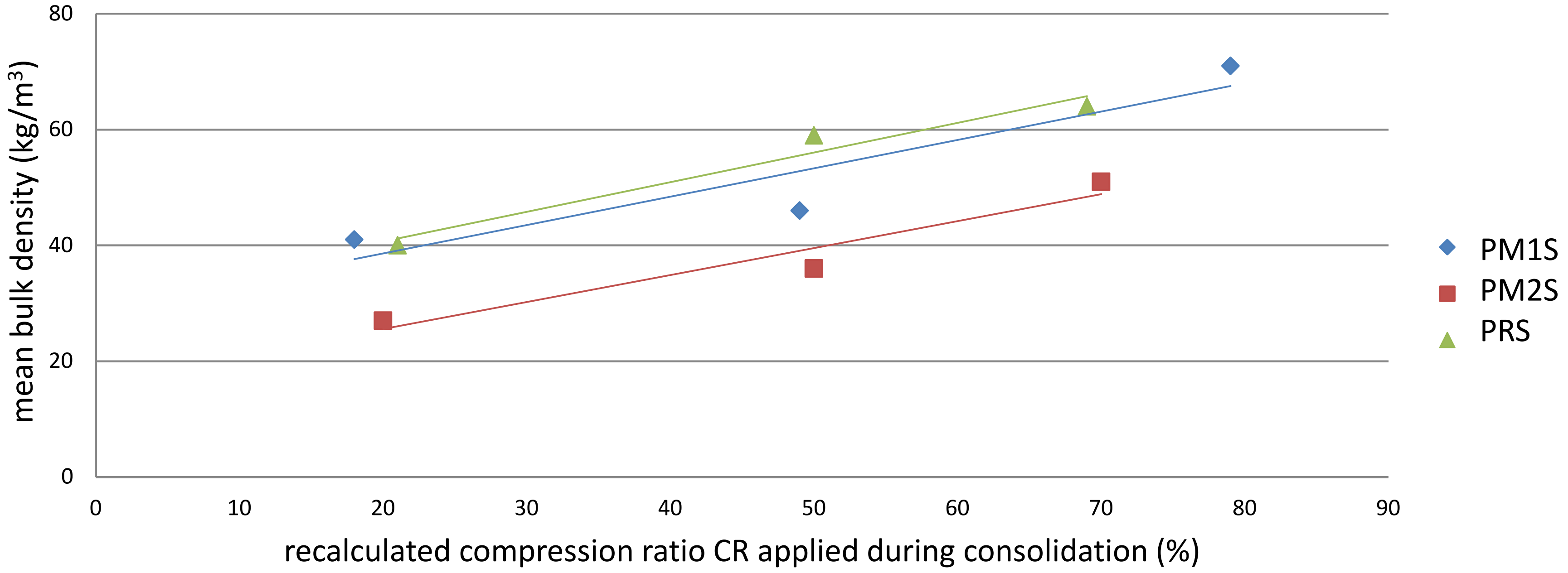
➔ PM2 and PR contain few non-defibrated elements

✓ PR contains 2.5 more fine elements than PM2 (opening<0.5mm)

➔ Can be explained by their anatomical difference

2. Variability of apparent bulk density of the 9 panels manufactured

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



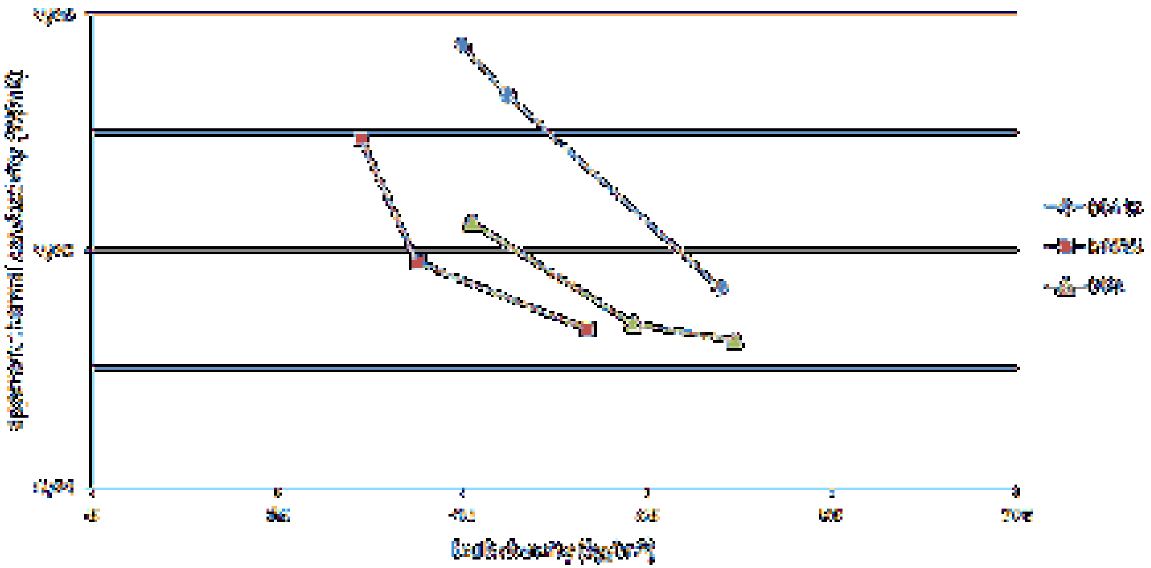
- ✓ Bulk densities ranging from 25 to 75 kg/m^3
- ✓ Process suitable for design of fibrous networks made up of fine wood fibres

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

3. Experimental values of apparent thermal conductivities of wood fibreboards

➔Note that during measurements (20°C/65%RH), moisture content at the equilibrium state of wood fibreboards is comprised between 10 and 11% by mass

Experimental values of apparent thermal conductivities function of bulk density for each blend of wood/synthetic fibres at 20°C/65%RH:



Apparent thermal conductivities:

➔ well correlated with bulk densities

➔ also influenced by the degree of destructuration of wood chips

4. Simulation modelling of apparent thermal conductivities / bulk density (1/5)

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

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

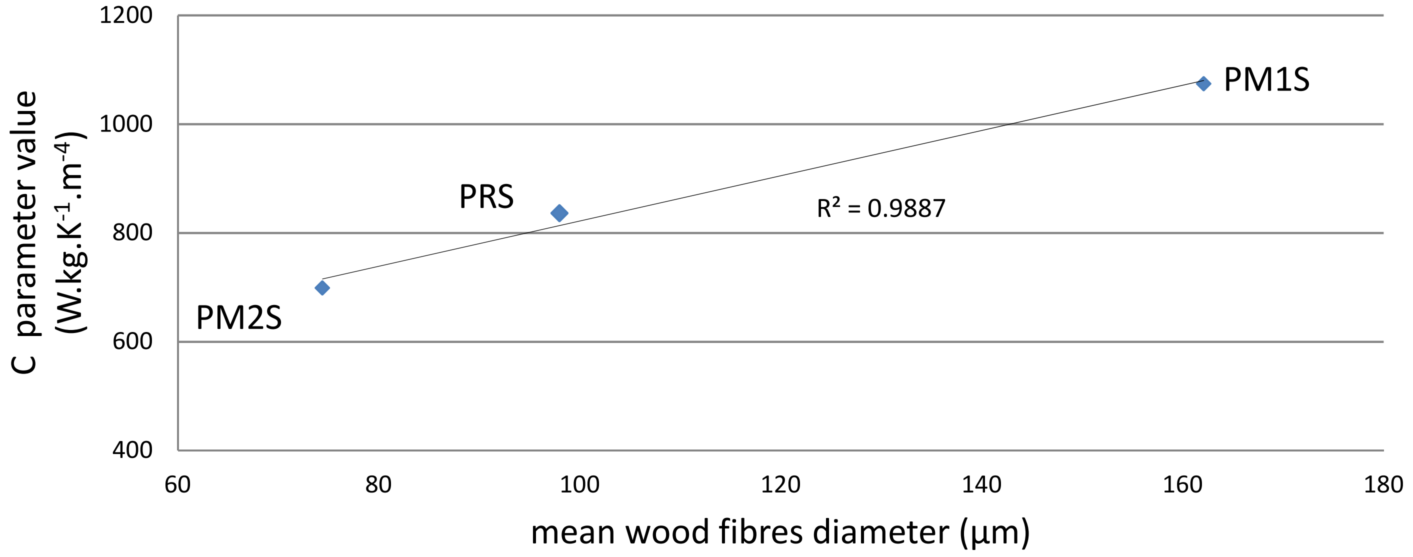
➔ *possible to simulate the development of the different modes of heat transfer inside fibrous insulating materials with regard to its density by considering:*

- *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 (2/5)

Influence of mean wood fibre diameter on C parameter value:

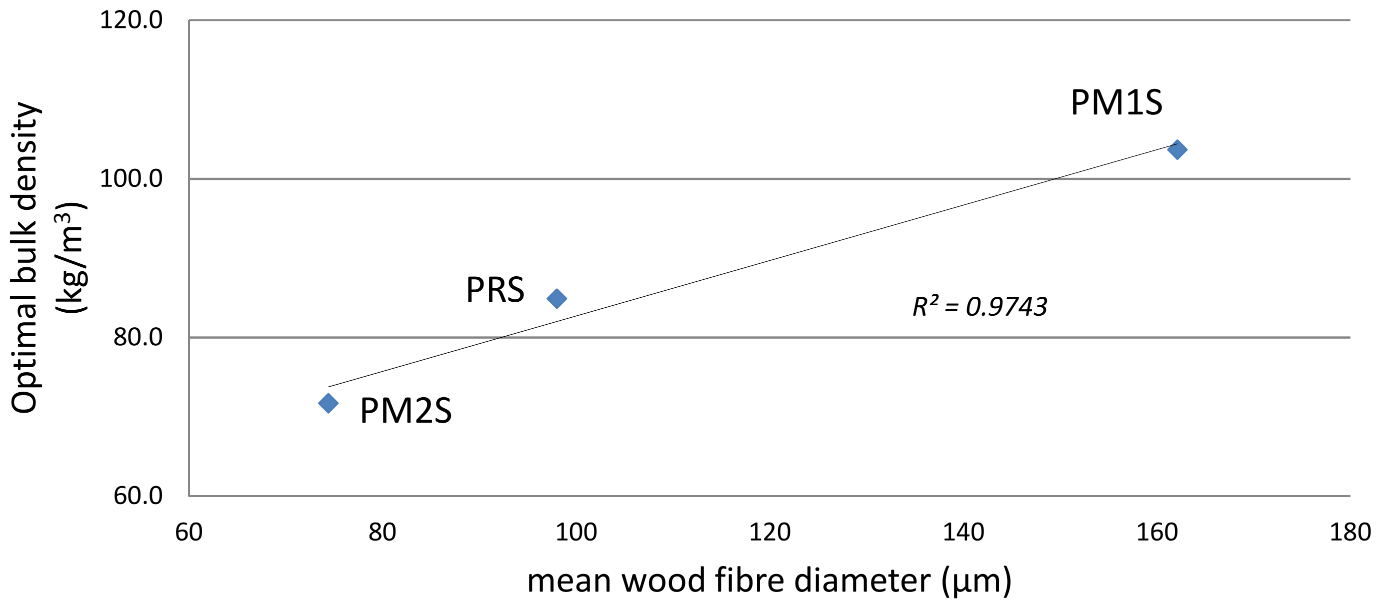


✓ Wood insulating board made up of finer fibres have a lower radiation contribution (“C/ρ”)

➔ *Consequently, use of 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 (3/5)

Influence of mean wood fibre diameter on optimal bulk density:

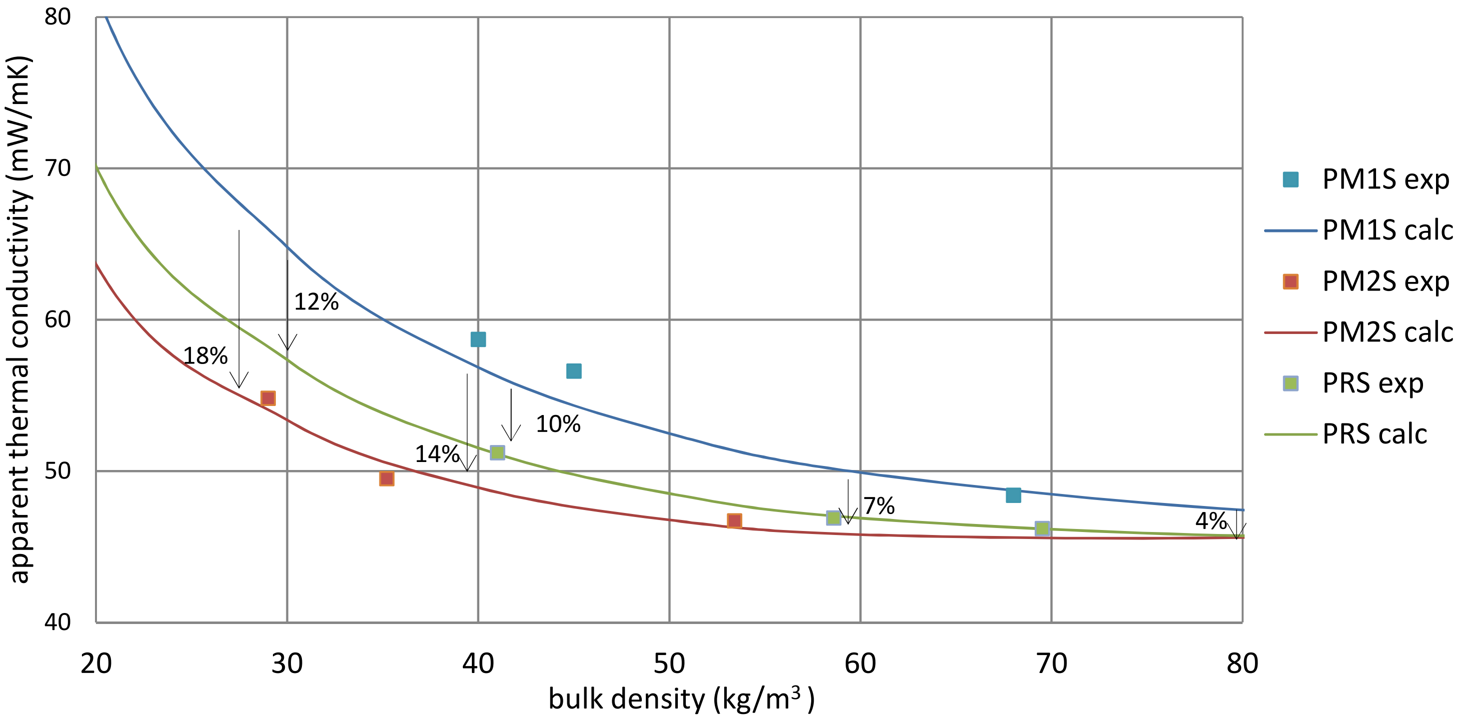


➔ Wood insulating board made up of finer fibres have a lower optimal bulk density

✓ *Use of finer fibres are better candidates when bulk densities are lower than 100 kg/m^3*

4. Simulation modelling of apparent thermal conductivities / bulk density (4/5)

Evolution of apparent thermal conductivities of the resultant wood fibreboards at low density at 20°C/65%RH:

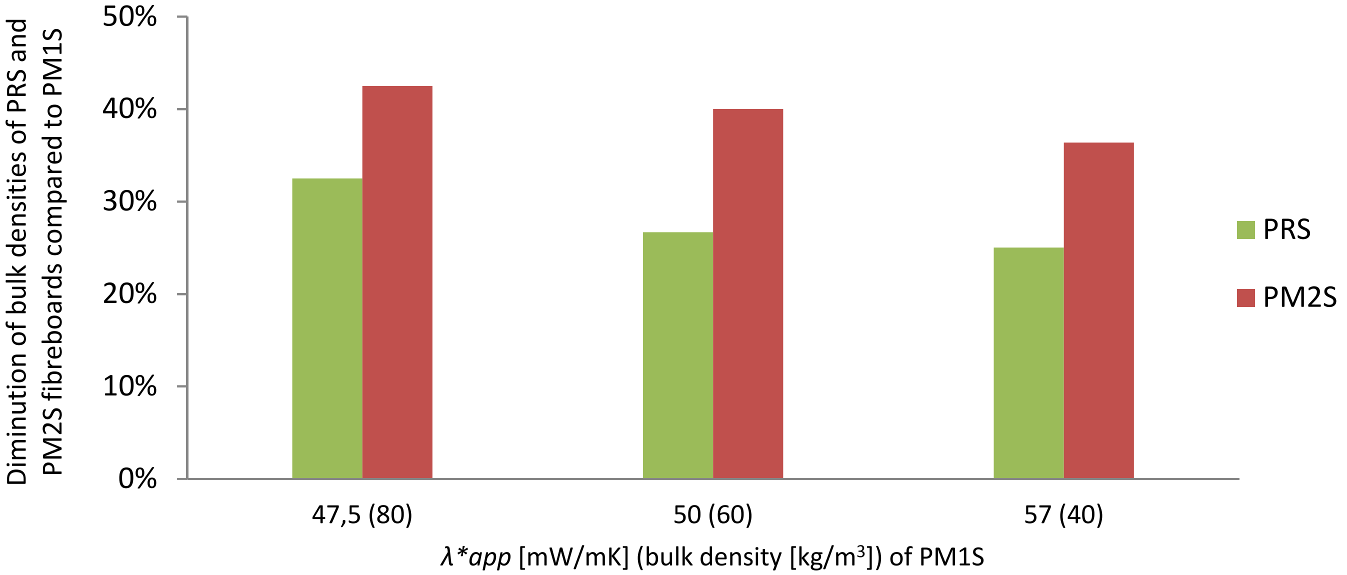


✓ *Influence of fine fibres on apparent thermal conductivity tends to be particularly important when bulk densities are very low*

➔ *PRS and PM2S have a quite similar evolution as long as $\rho^* > 50$ kg/m³*

4. Simulation modelling of apparent thermal conductivities / bulk density (5/5)

*Diminution of bulk densities of PRS and PM2S fibreboards compared to PM1S while having same values of λ*app at 20°C/65%RH than PM1S:*



➔ Use of finer fibres is also a solution to decrease renewable raw materials quantity constitutive of insulations (lower bulk density than PM1S at same value of *λ*app*)

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

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

- *Poplar could be valorised as wood fibre-based thermal insulation materials*

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 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*

Thanks for attention!