nZEBIO

Adoption of V4 buildings to nZEB standard using natural and bio-based materials

Olsztyn 09. – 12. 09. 2021

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CHARACTERISATION, APPLICATION AND TECHNICAL VALUE ANALYSIS OF NATURAL AND RECYCLED THERMAL INSULATIONS

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Characterisation: feather fibre fabric & others

(a) Feather fibre fabric, density 29.8 kg/m^3

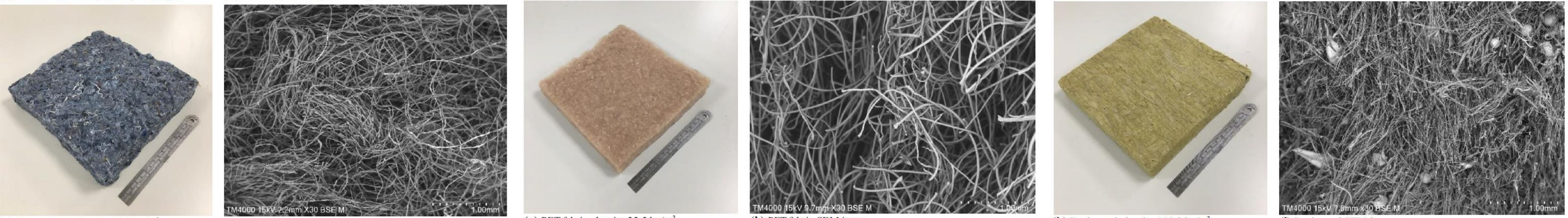
(b) Feather fibre fabric SEM image

(e) Hemp fabric, density 83.3 kg/m^3

(f) Hemp fibre fabric SEM image

(i) Sheep wool fabric, density 47.6 kg/m^3

(j) Sheep wool SEM image



(c) Denim fabric, density 30.0 kg/m^3

(d) Denim fibre fabric SEM image

(g) PET fabric, density 25.5 kg/m^3

(h) PET fabric SEM image

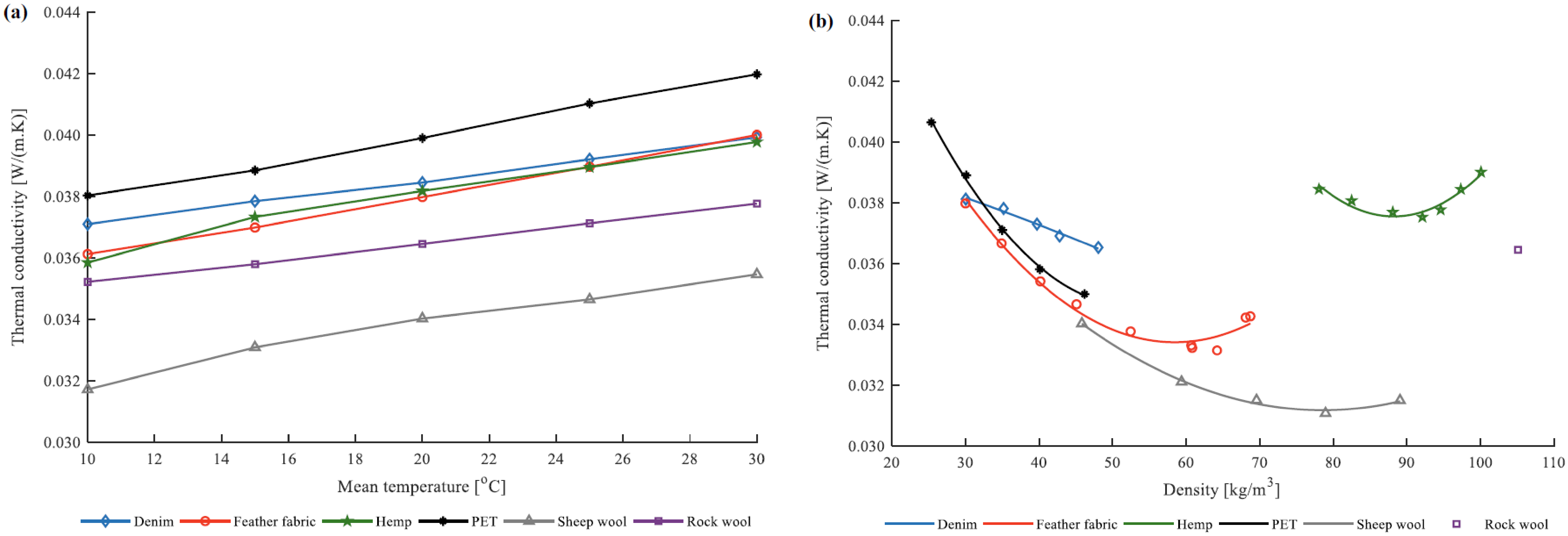
(k) Rock wool, density 110.3 kg/m^3

(l) Rock wool SEM image

Images of the feather fibre fabric produced in this study and the commercially available thermal insulation materials tested for comparison. Scanning electron microscope images of the microstructure of each material are also shown.

https://doi.org/10.1007/s12649-020-01007-3

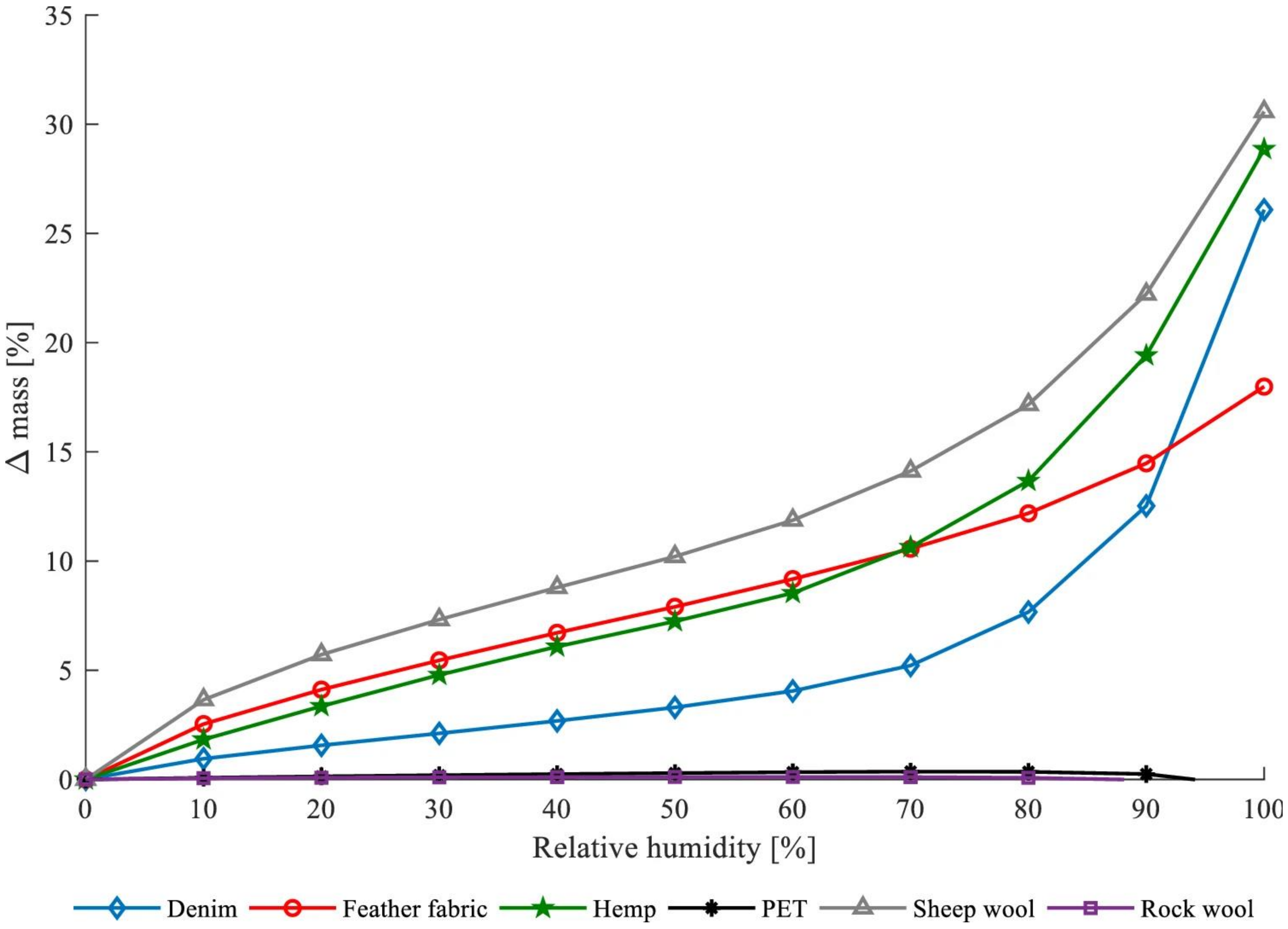
Characterisation: feather fibre fabric & others



Thermal conductivity data for feather fibre fabric and commercially available thermal insulation materials (tested at 20ºC, ΔT = 10 °C).
a Effect of test temperature on thermal conductivity, **b** effect of sample density on thermal conductivity

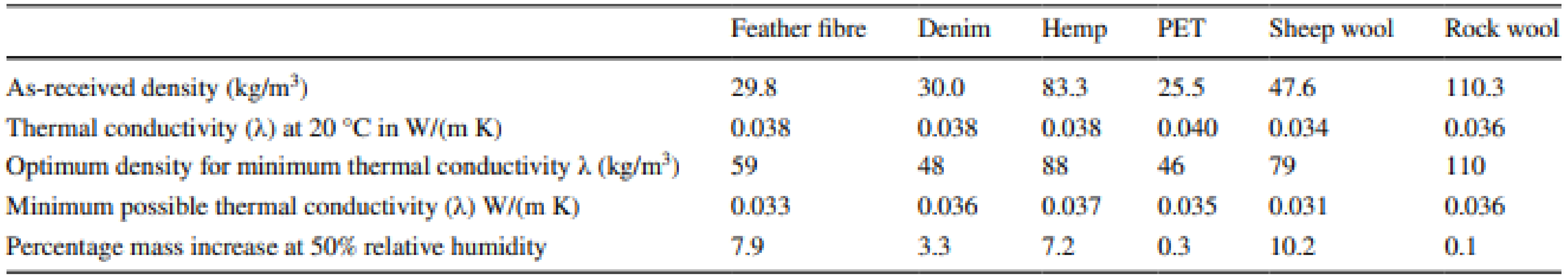
https://doi.org/10.1007/s12649-020-01007-3

Characterisation: feather fibre fabric & others



DVS data for feather fibre fabrics and commercially available thermal insulation materials

Summary of key thermal property characterisation results for different thermal insulation materials:



	Feather fibre	Denim	Hemp	PET	Sheep wool	Rock wool
As-received density (kg/m^3)	29.8	30.0	83.3	25.5	47.6	110.3
Thermal conductivity (λ) at 20 °C in W/(m K)	0.038	0.038	0.038	0.040	0.034	0.036
Optimum density for minimum thermal conductivity λ (kg/m^3)	59	48	88	46	79	110
Minimum possible thermal conductivity (λ) W/(m K)	0.033	0.036	0.037	0.035	0.031	0.036
Percentage mass increase at 50% relative humidity	7.9	3.3	7.2	0.3	10.2	0.1

https://doi.org/10.1007/s12649-020-01007-3

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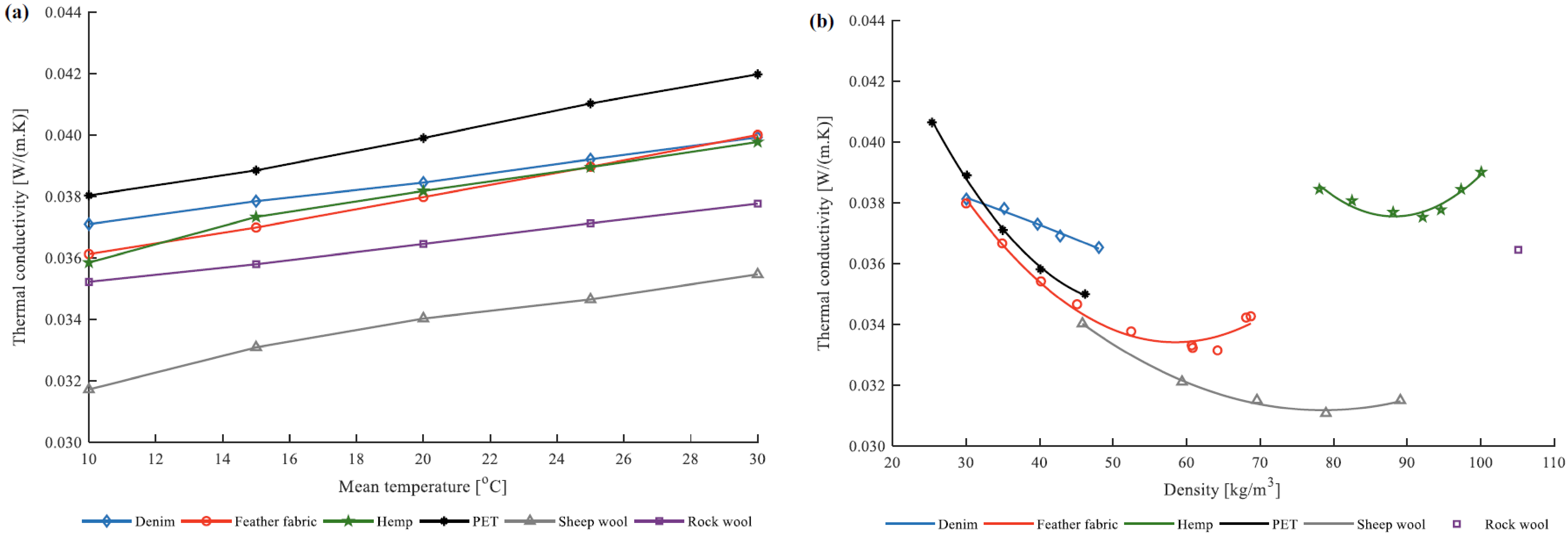
Characterisation: feather fibre fabric & others



Thermal conductivity data for feather fibre fabric and commercially available thermal insulation materials (tested at 20ºC, ΔT = 10 °C). **a** Effect of test temperature on thermal conductivity, **b** effect of sample density on thermal conductivity

https://doi.org/10.1007/s12649-020-01007-3

Characterisation: wheat and barley straw bulks

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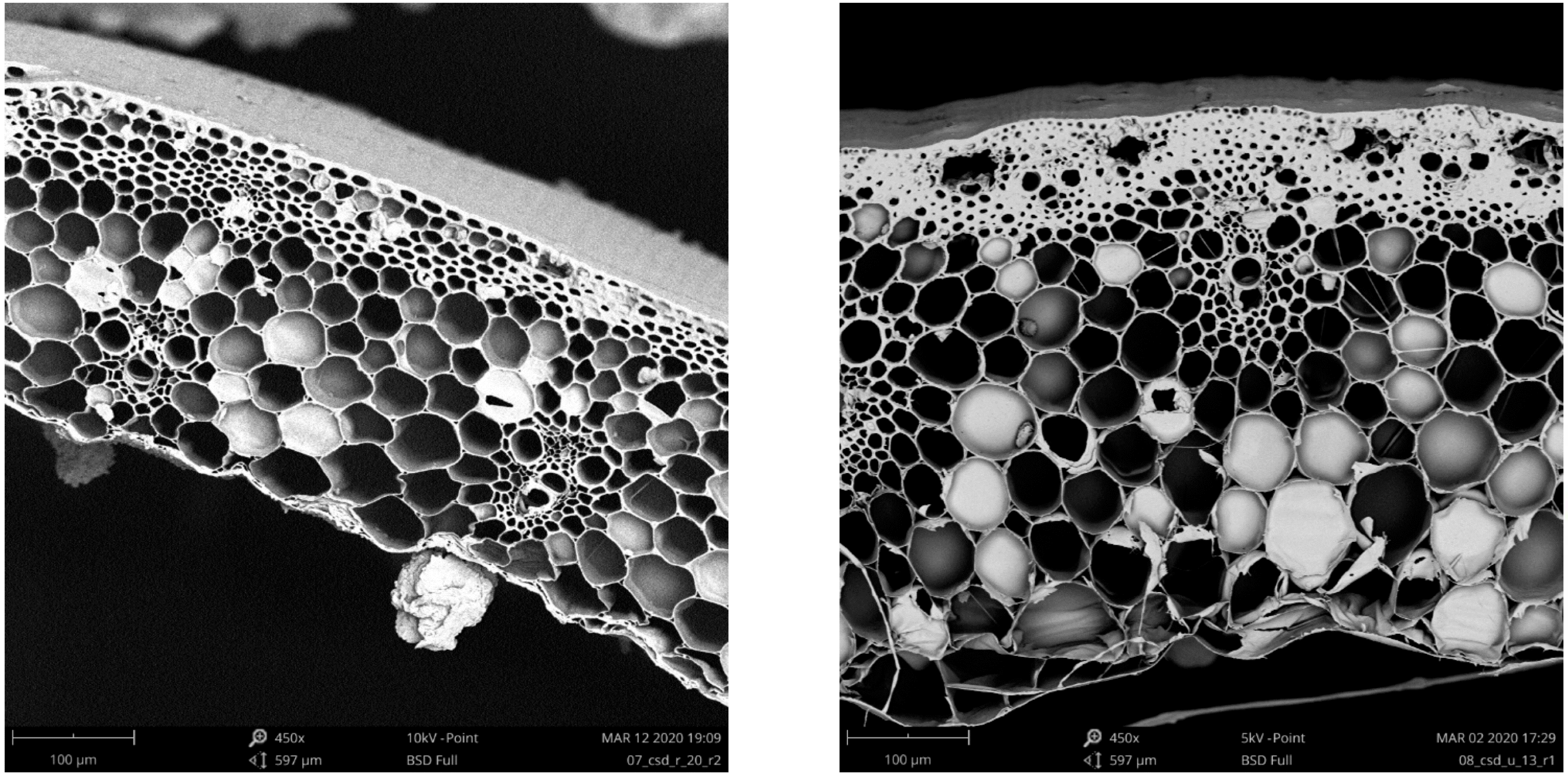
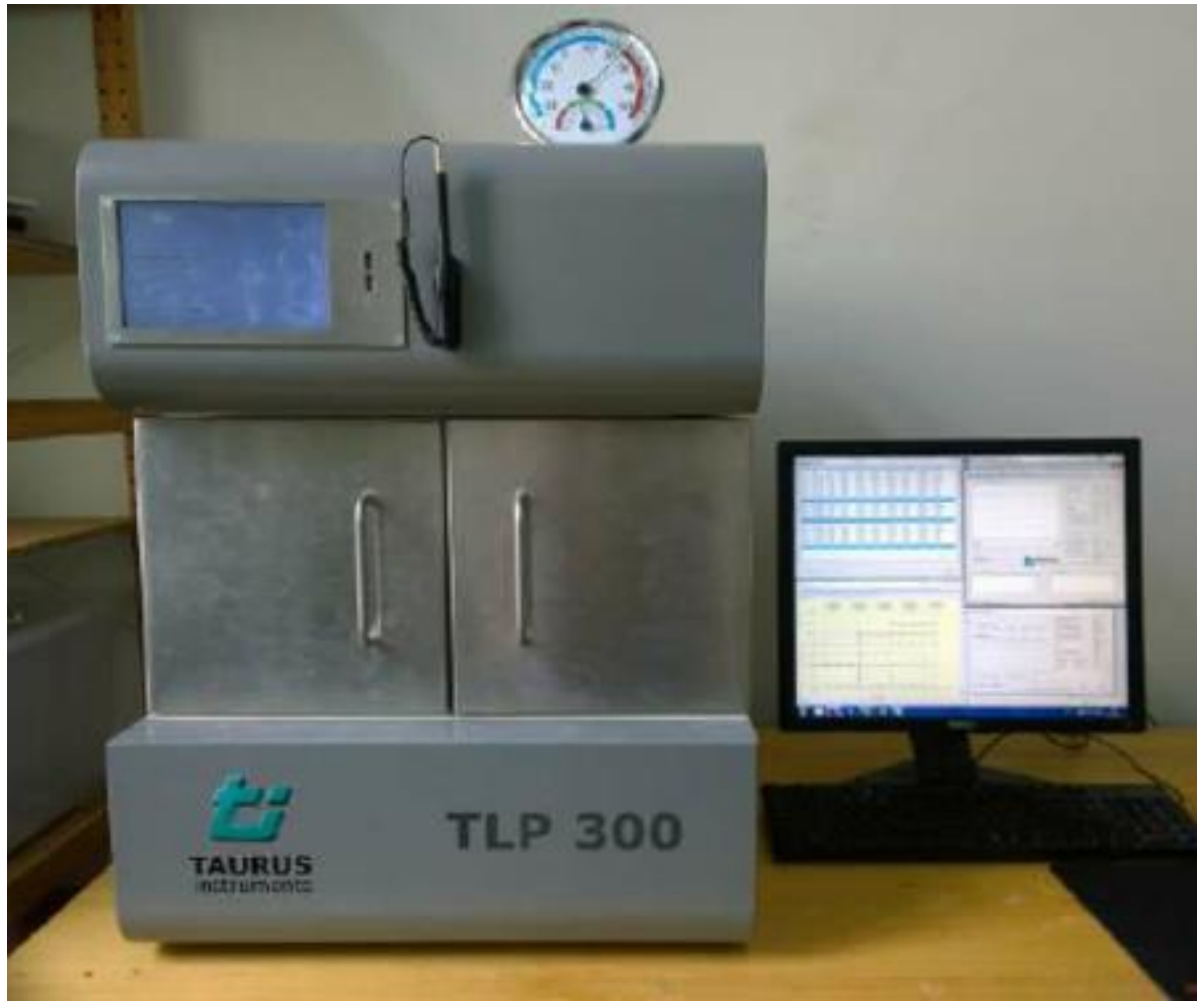


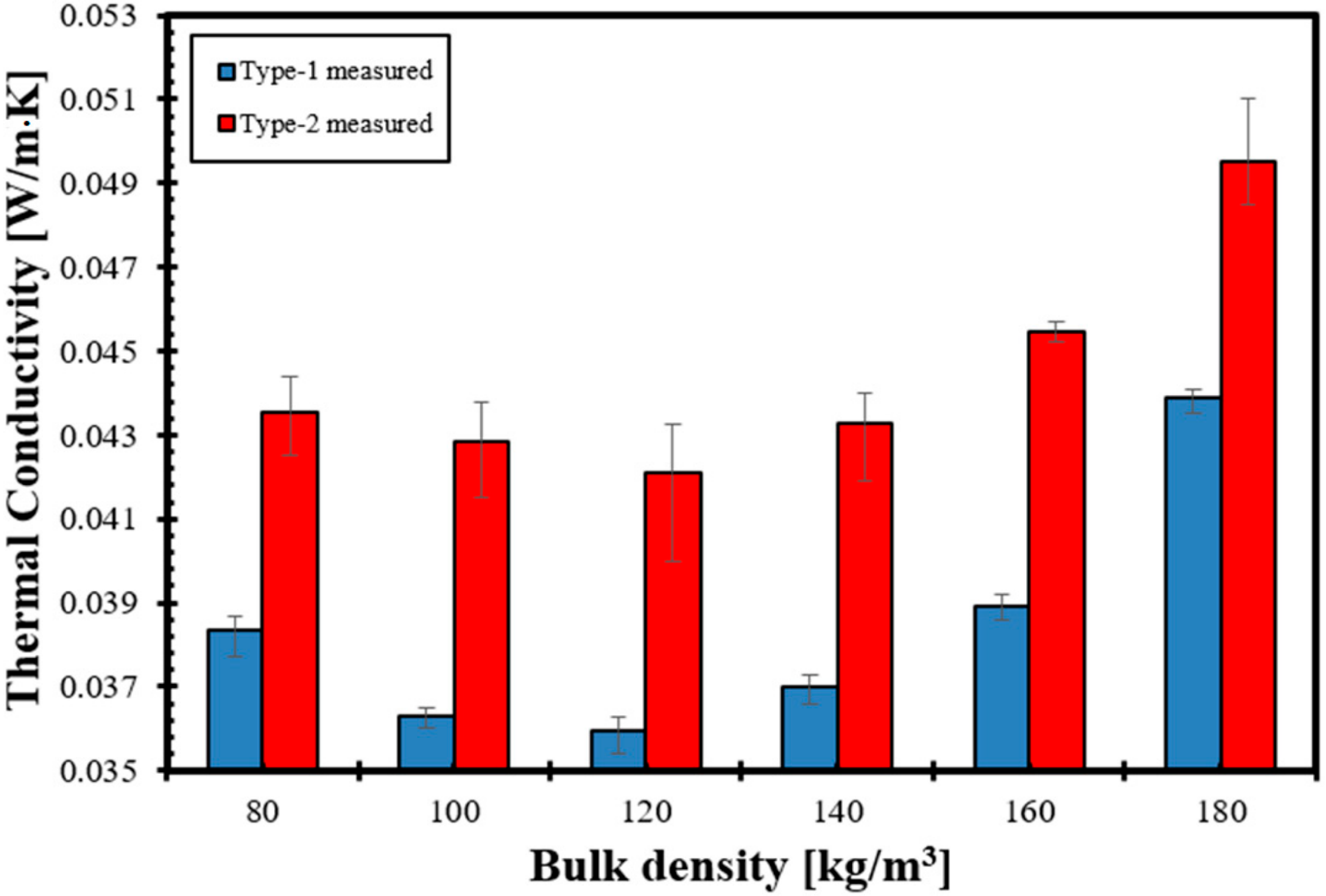
(**a**) (**b**)

SEM images in 450× magnification of: (**a**) Type-1: Barley straw stem; (**b**) Type-2: Wheat straw.

https://doi.org/10.3390/ma14164408

Characterisation: wheat and barley straw bulks

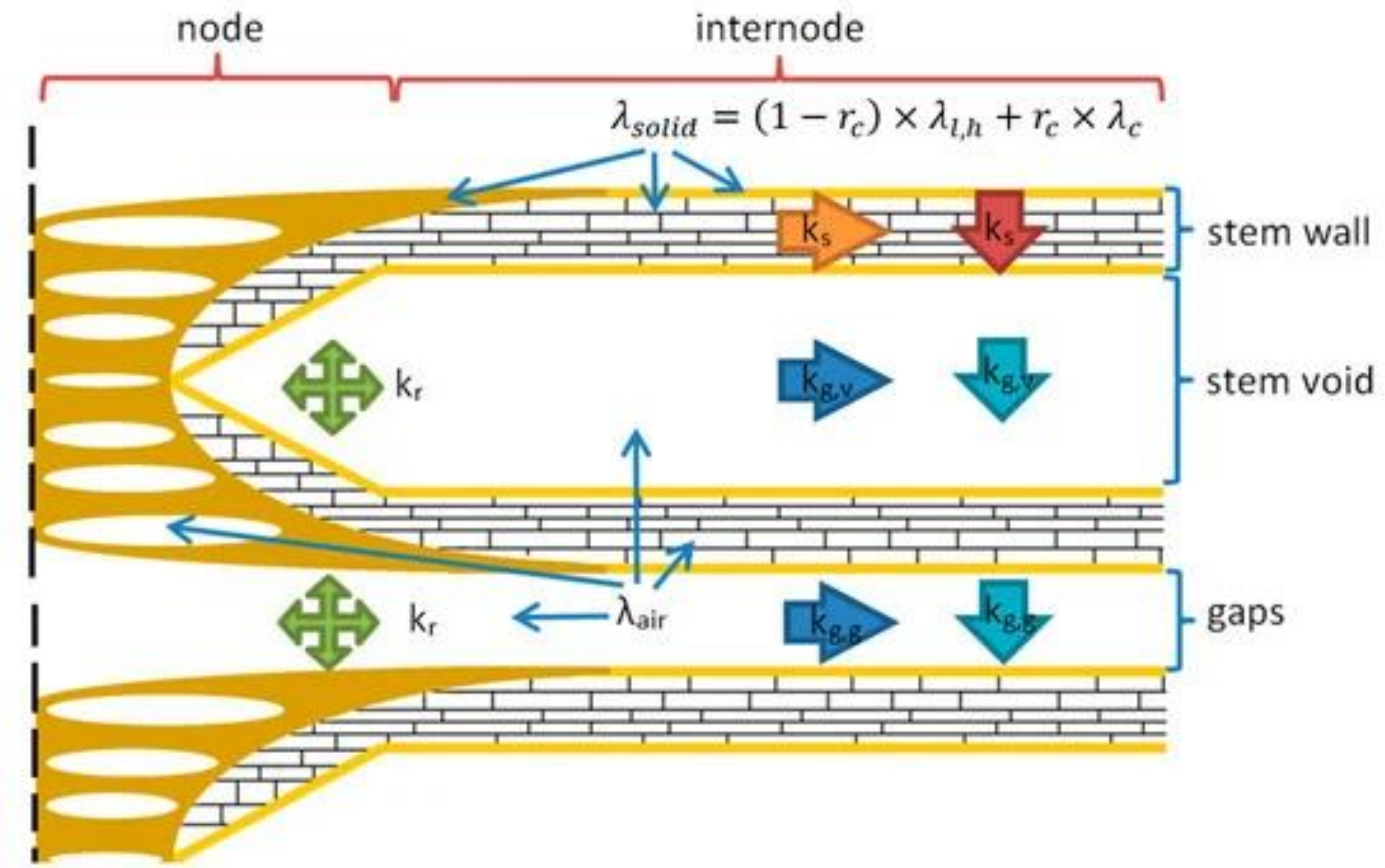


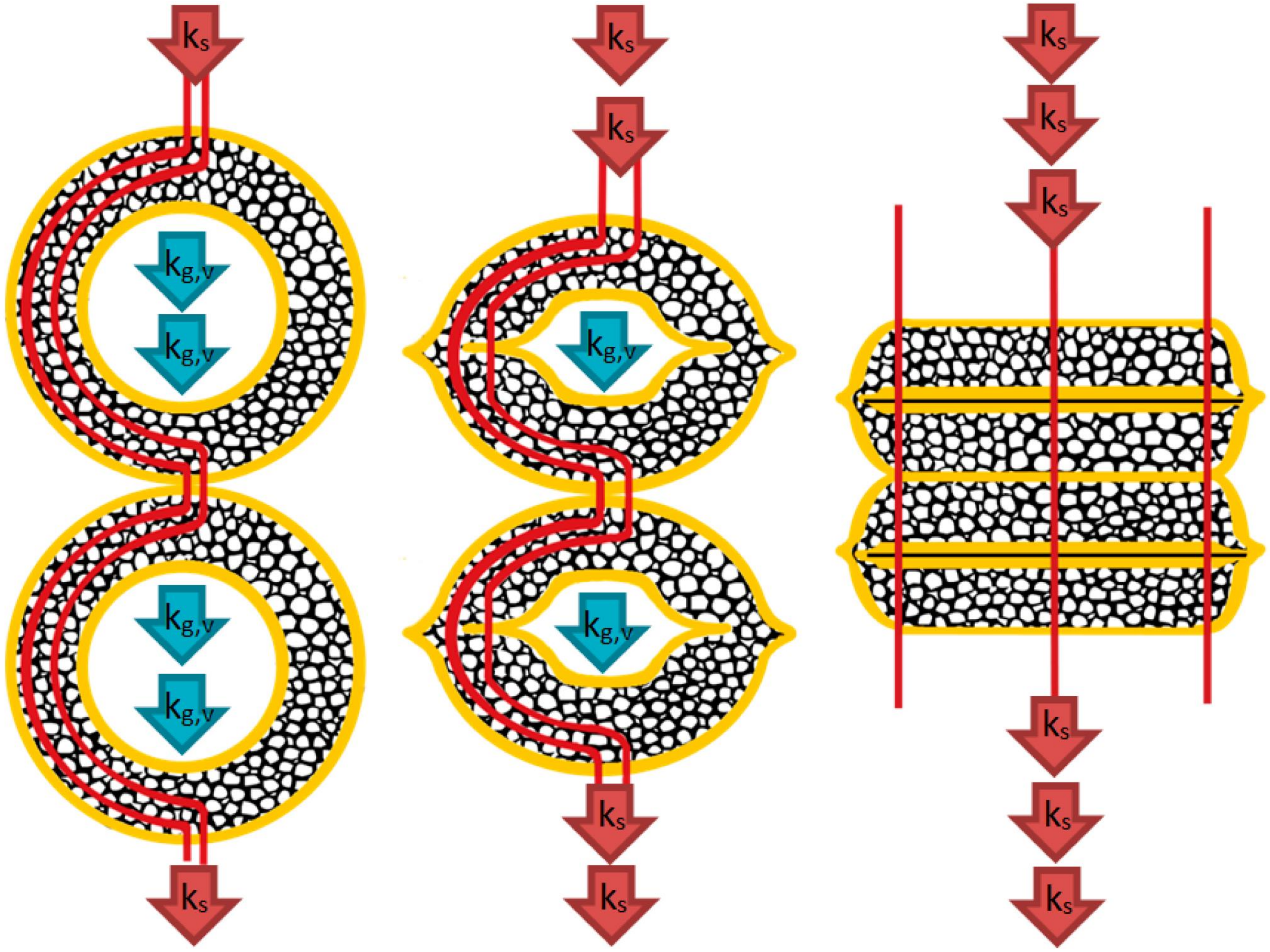


Measured thermal conductivity using GHP of randomly oriented Type-1 and Type-2 straw bulks with different bulk densities.
Type-1: Barley straw; Type-2: Wheat straw.

https://doi.org/10.3390/ma14164408

Characterisation: wheat and barley straw bulks





Heat Transfer in Straw-Based Thermal Insulating Materials:

- k_s—conduction through the solid medium (fibers), this component includes the heat transfer in the natural composite and in its embedded air pores;
- $k_{g.tot}$—conduction through gas medium including:
- $k_{g.g}$—conduction in the air trapped in gaps among the stems,
- $k_{g.v}$—conduction in the voids of stems;
- k_r—radiative heat transfer;
- k_{conv}—convection in the air in gaps between the fibers.

https://doi.org/10.3390/ma14164408

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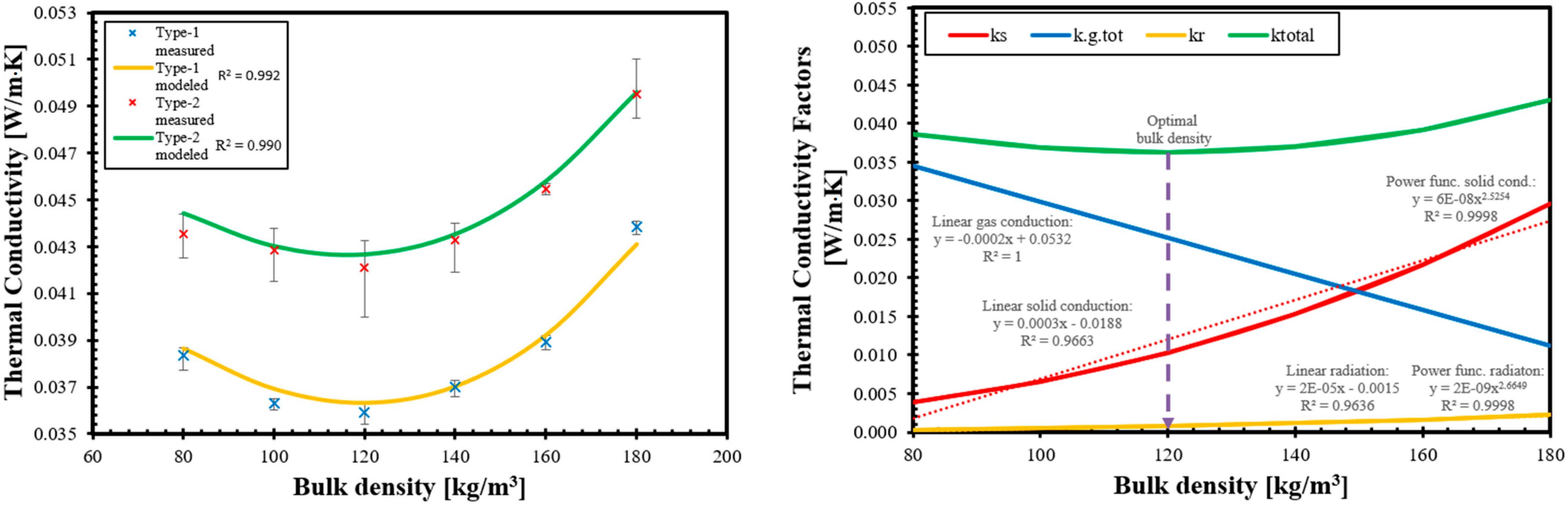
Characterisation: wheat and barley straw bulks



Relationship between bulk density and total thermal conductivity in case of the results of laboratory measurements and the analytic-empirical model using Type-1: Barley and Type-2: Wheat straws.

https://doi.org/10.3390/ma14164408

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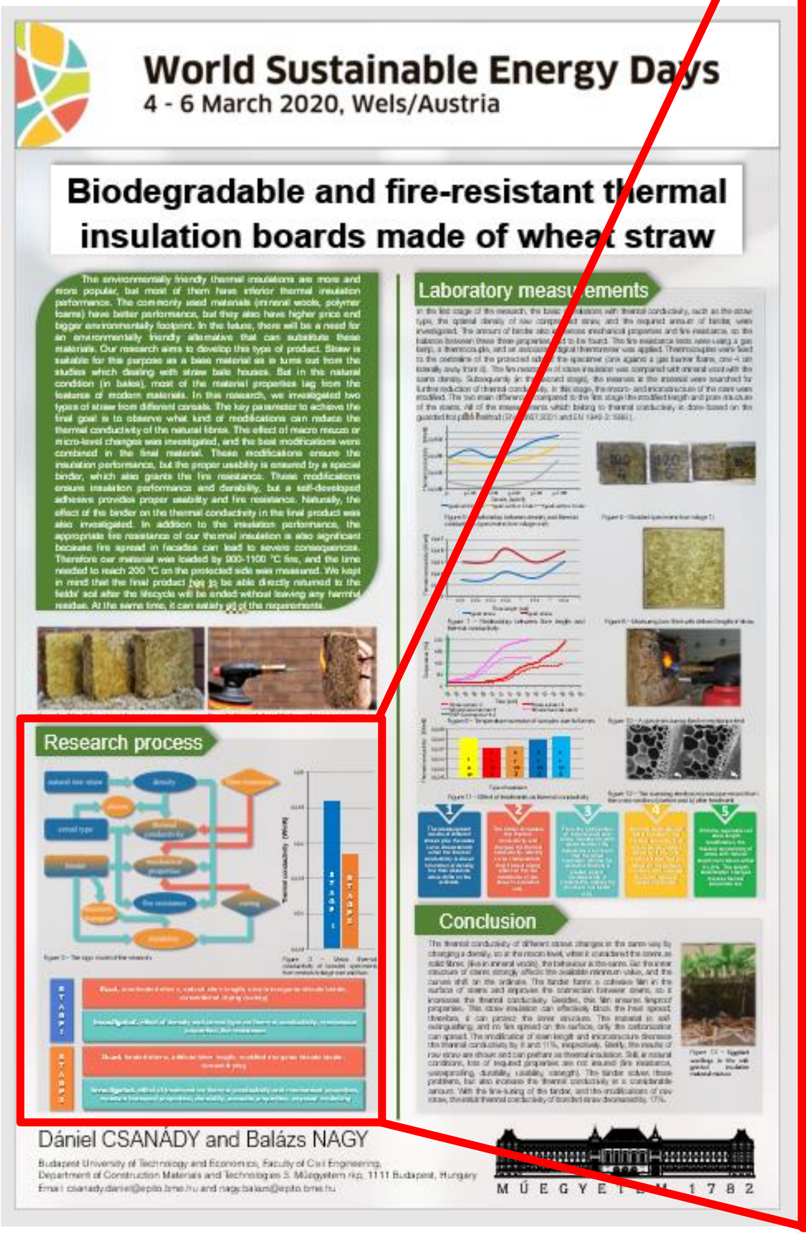
Application: straw thermal insulation panels


World Sustainable Energy Days
4 - 6 March 2020, Wels/Austria

Biodegradable and fire-resistant thermal insulation boards made of wheat straw

Laboratory measurements

Research process

Conclusion

Dániel CSANÁDY and Balázs NAGY

Research process

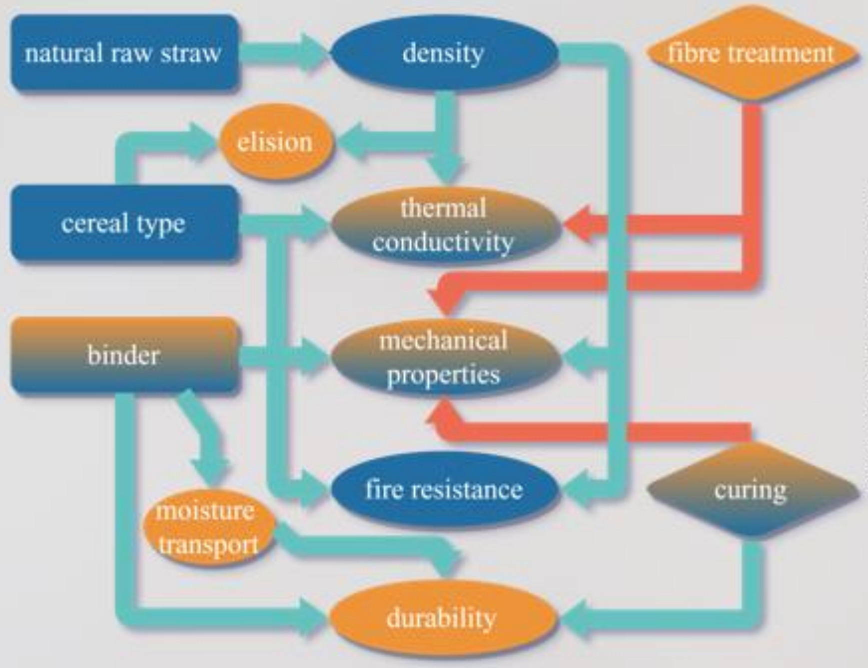


Figure 3 – The logic model of the research

Figure 3 – Mean thermal conductivity of bonded specimens from research stage one and two

STAGE 1

Used: non-treated stems, natural stem length, simple inorganic silicate binder, conventional drying (curing)

Investigated: effect of density and cereal type on thermal conductivity, mechanical properties, fire resistance

STAGE 2

Used: treated stems, artificial stem length, modified inorganic silicate binder, special drying

Investigated: effect of treatment on thermal conductivity and mechanical properties, moisture transport properties, durability, acoustic properties, physical modelling

W-HEAT

https://w-heat.hu

Application: ventilated double-skin cold roofs

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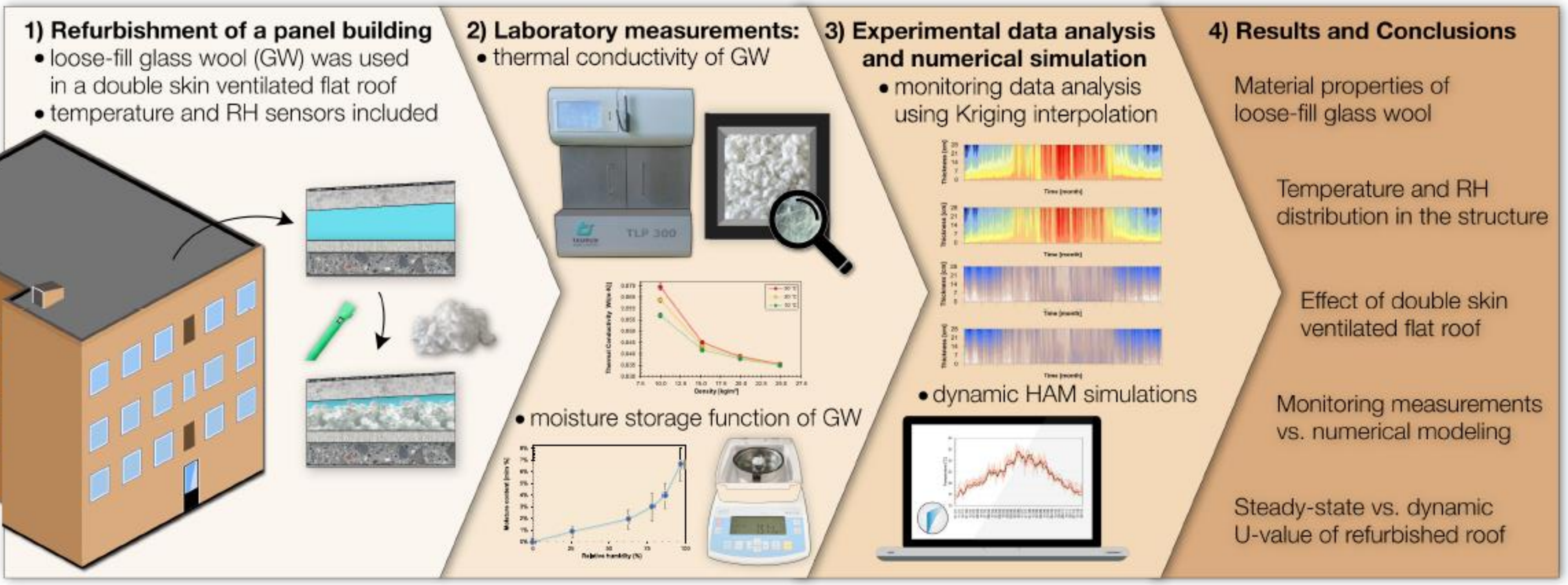


1) Refurbishment of a panel building
- loose-fill glass wool (GW) was used in a double skin ventilated flat roof
- temperature and RH sensors included

2) Laboratory measurements:
- thermal conductivity of GW
- moisture storage function of GW

3) Experimental data analysis and numerical simulation
- monitoring data analysis using Kriging interpolation
- dynamic HAM simulations

4) Results and Conclusions

Material properties of loose-fill glass wool

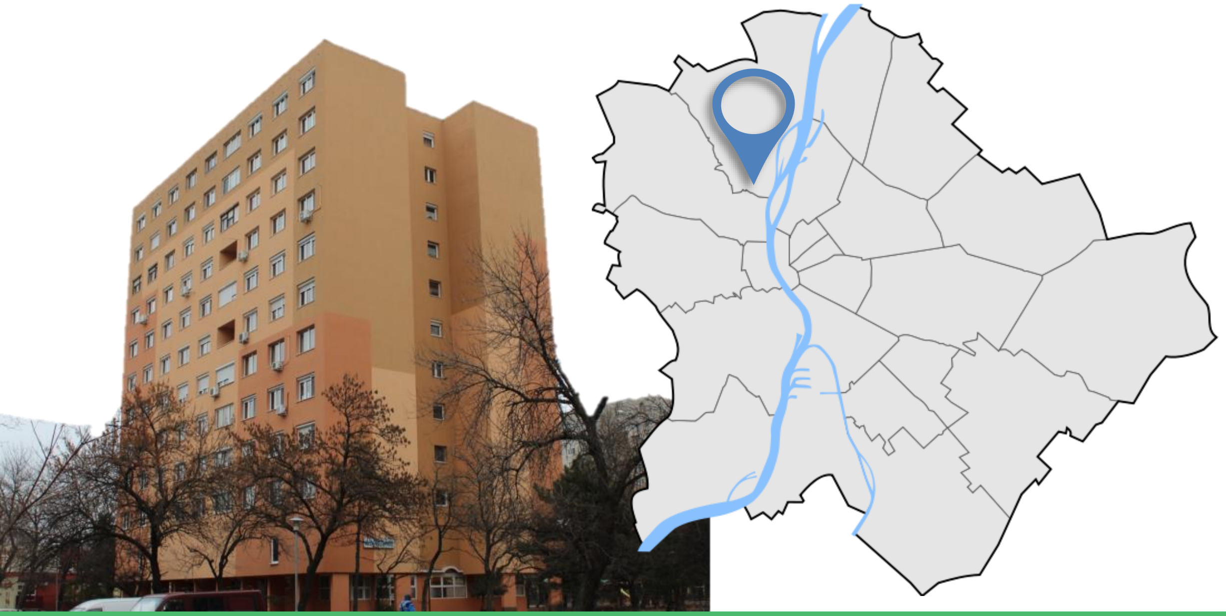
Temperature and RH distribution in the structure

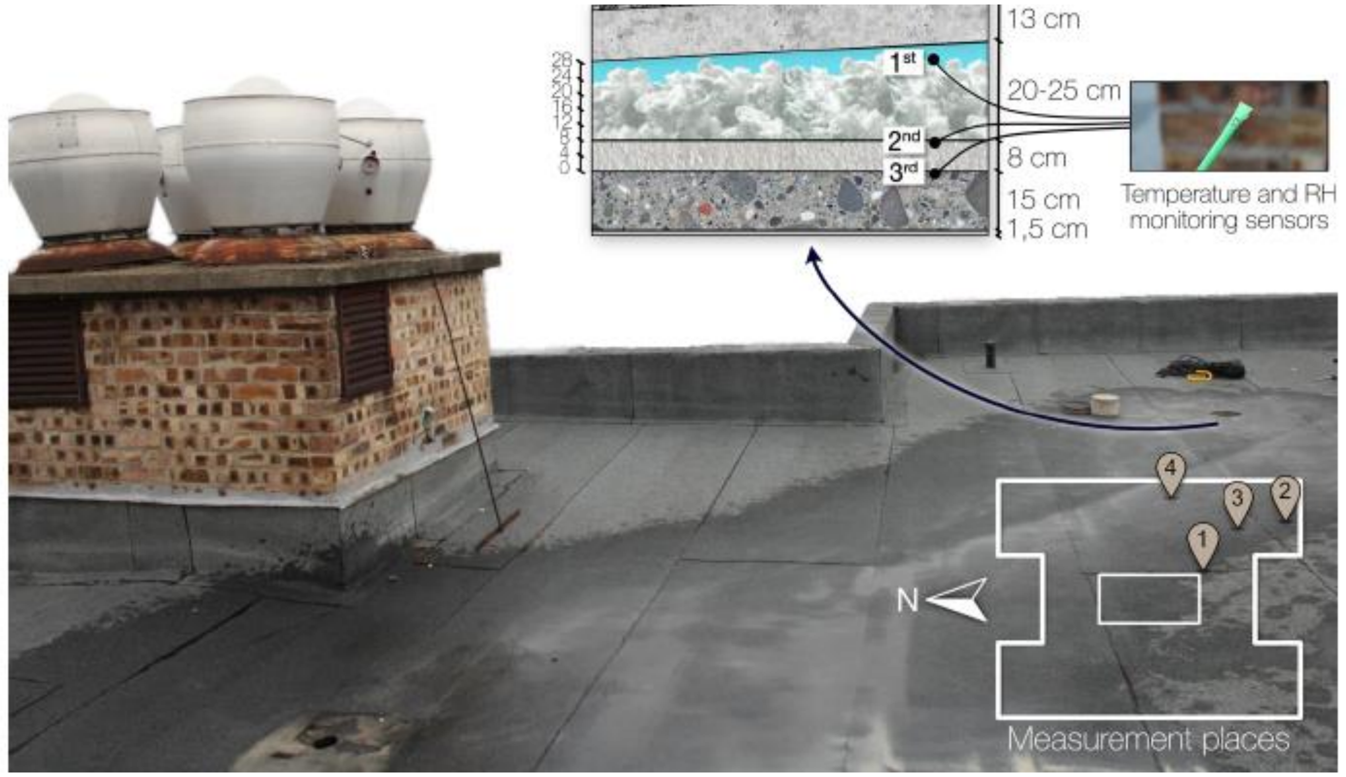
Effect of double skin ventilated flat roof

Monitoring measurements vs. numerical modeling

Steady-state vs. dynamic U-value of refurbished roof

Szél utca, Budapest III. kerület





Blowing mineral wool (Supafil) made using 60% recycled glass

https://doi.org/10.1016/j.csite.2021.100941
https://doi.org/10.2478/9788395669699-032

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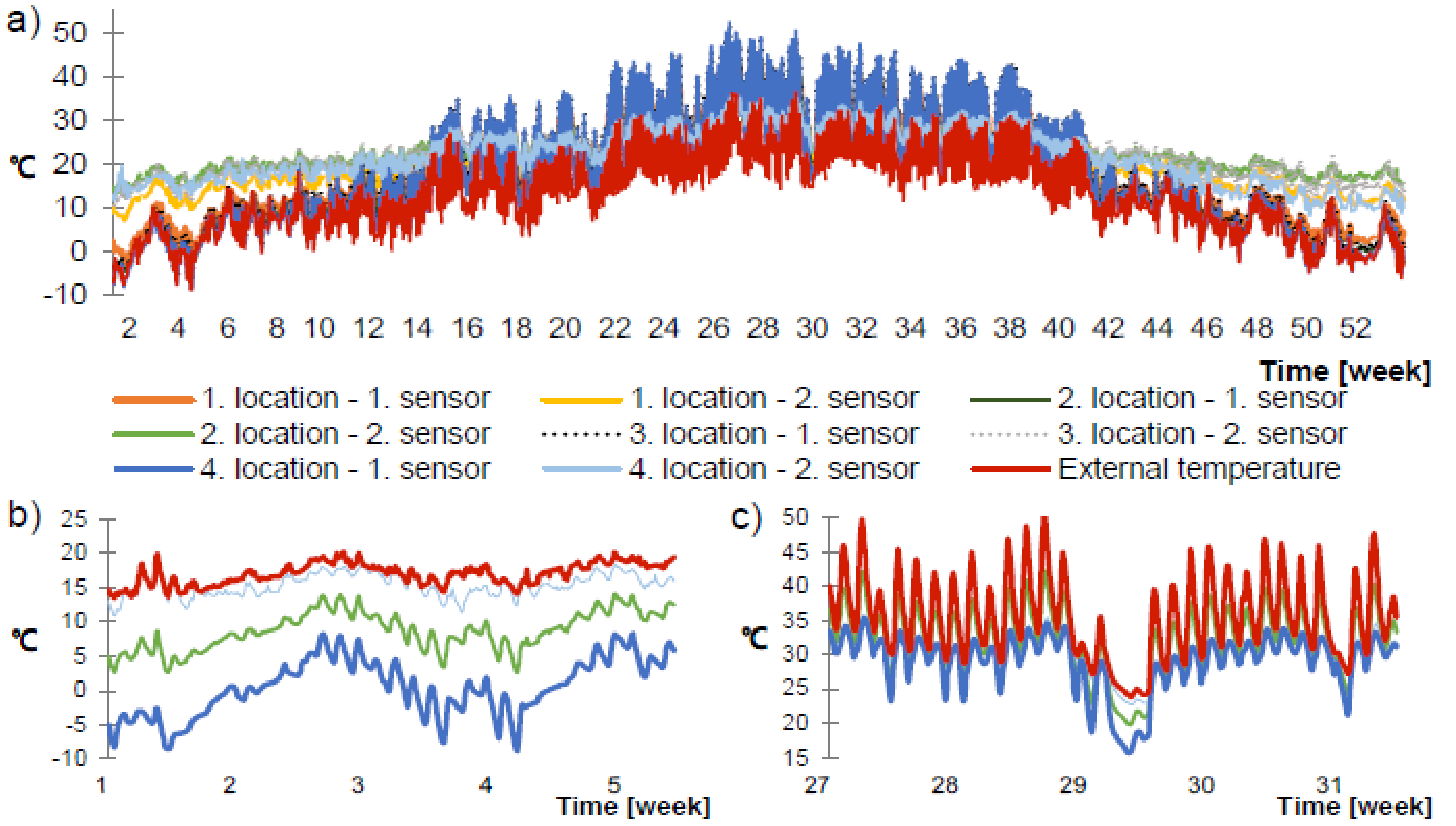
Application: ventilated double-skin cold roofs



a) temperature distribution in different measurement points during a year, b) temperature distribution in January, c) temperature distribution in July

Sensor placement in the roof structure, insulating process & measurement results of sensors

https://doi.org/10.1016/j.csite.2021.100941
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Application: ventilated double-skin cold roofs

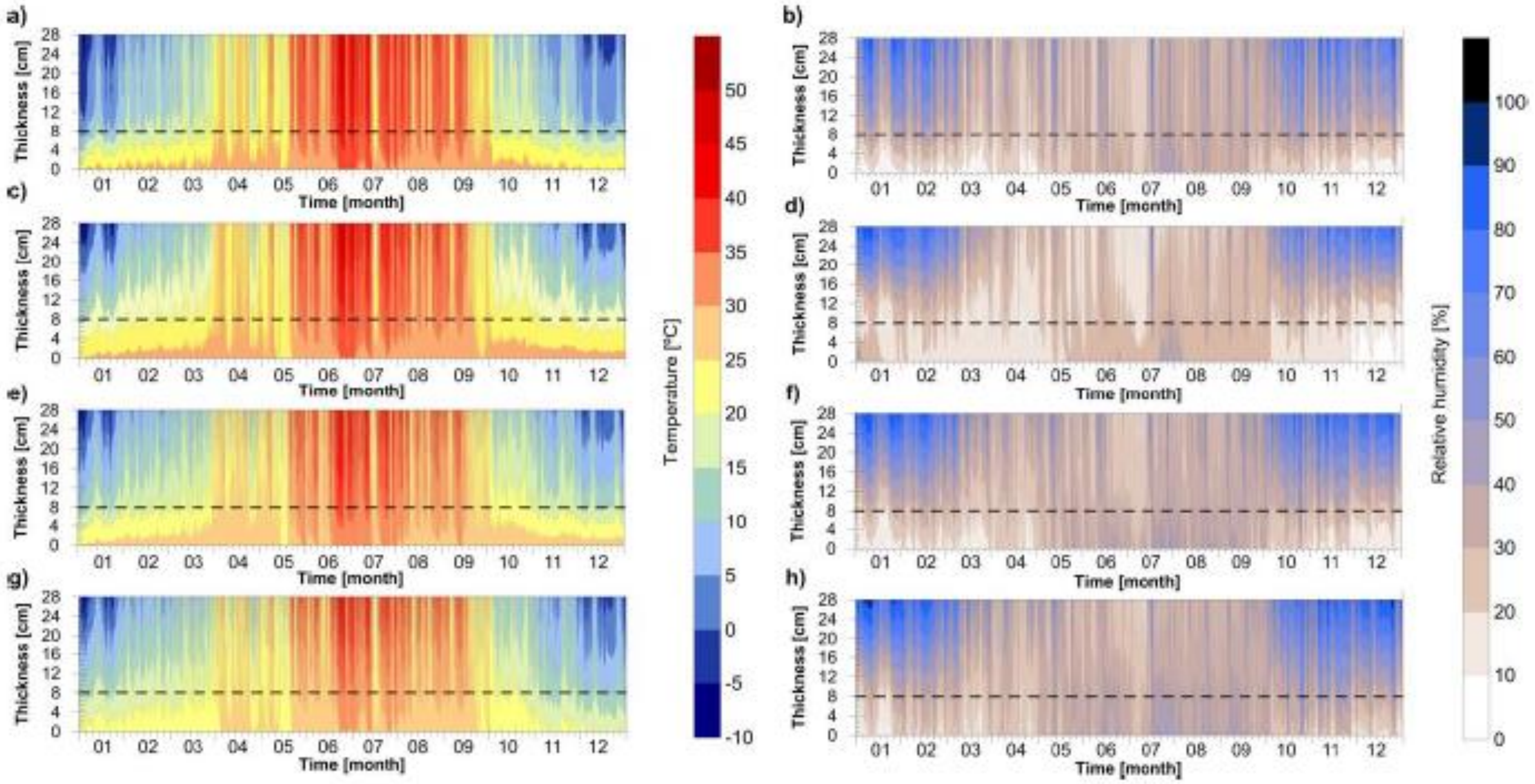
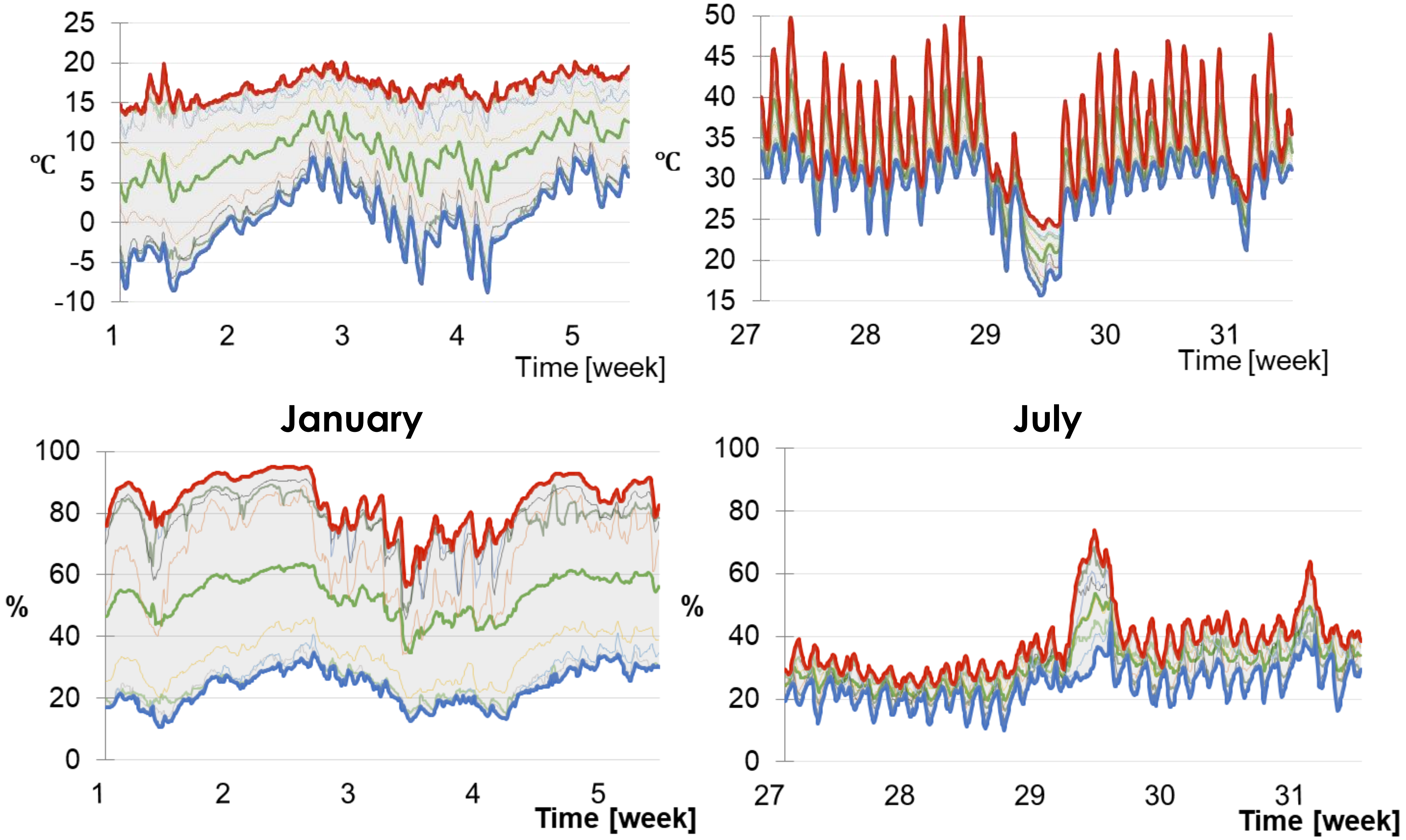


Fig. 2 *Measured and interpolated values during a year: a) Temperature of the 1st place, b) RH of the 1st place, c) Temperature of the 2nd place, d) RH of the 2nd place, e) Temperature of the 3rd place, f) RH of the 3rd place, g) Temperature of the 4th place, h) RH of the 4th place*



Measured temperature and relative humidity distribution across the construction

https://doi.org/10.1016/j.csite.2021.100941
https://doi.org/10.2478/9788395669699-032

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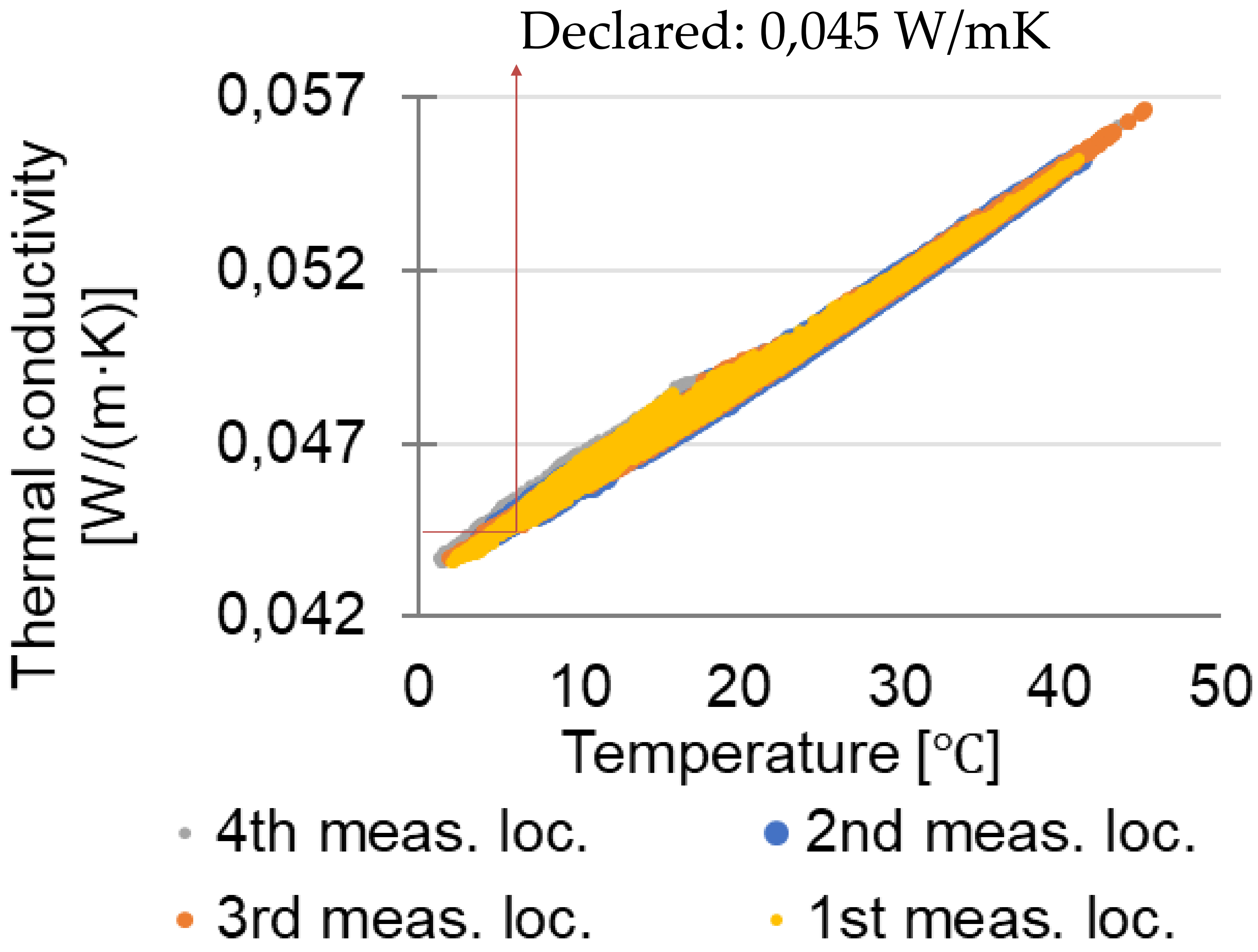
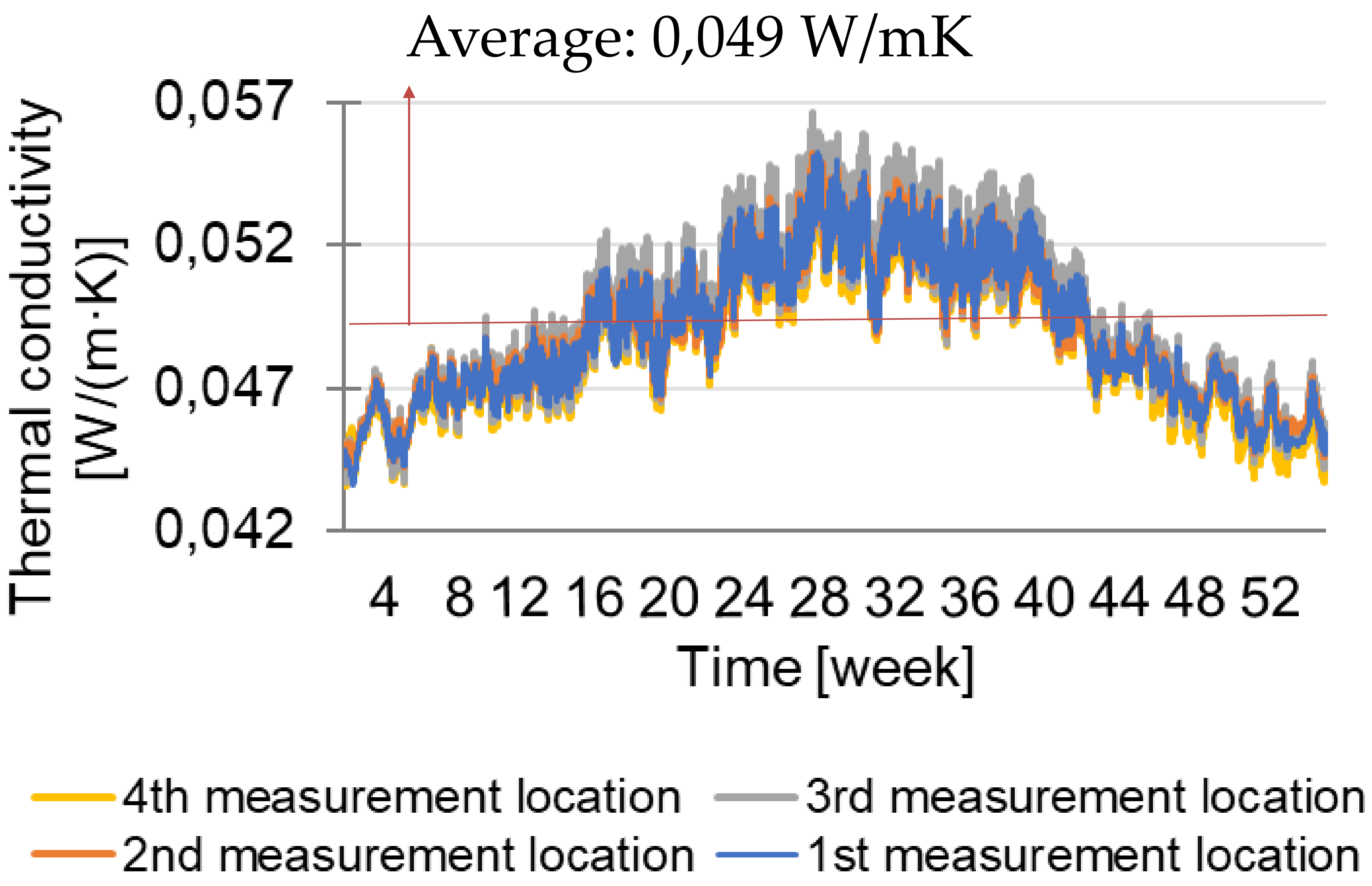
Application: ventilated double-skin cold roofs





$$\lambda_2 = \lambda_1 \cdot e^{ft(T2-T1)} \cdot e^{fu(U2-U1)}$$

https://doi.org/10.1016/j.csite.2021.100941
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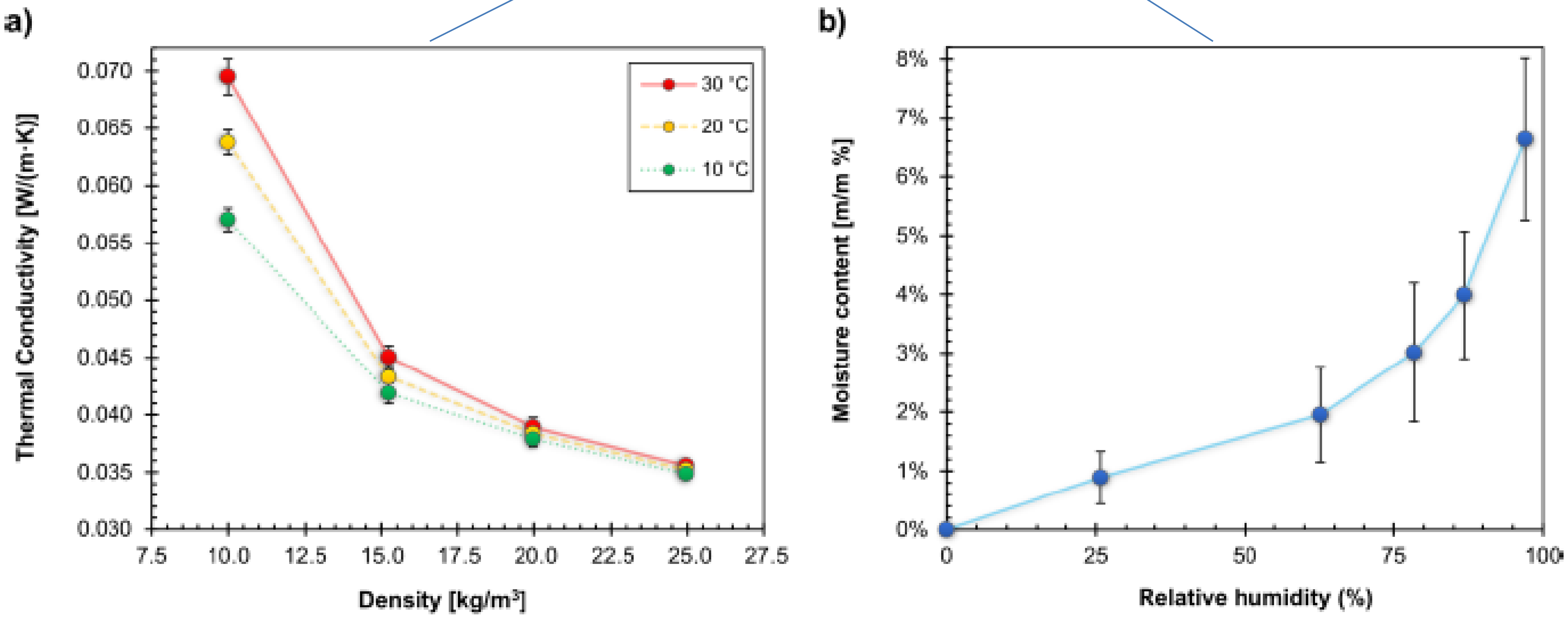
Application: ventilated double-skin cold roofs

$$\lambda_2 = \lambda_1 \cdot e^{ft(T2-T1)} \cdot e^{fu(U2-U1)}$$



Laboratory measurements results of glass wool: a) thermal conductivity at different density and temperature b) moisture storage function

https://doi.org/10.1016/j.csite.2021.100941
https://doi.org/10.2478/9788395669699-032

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Application: ventilated double-skin cold roofs

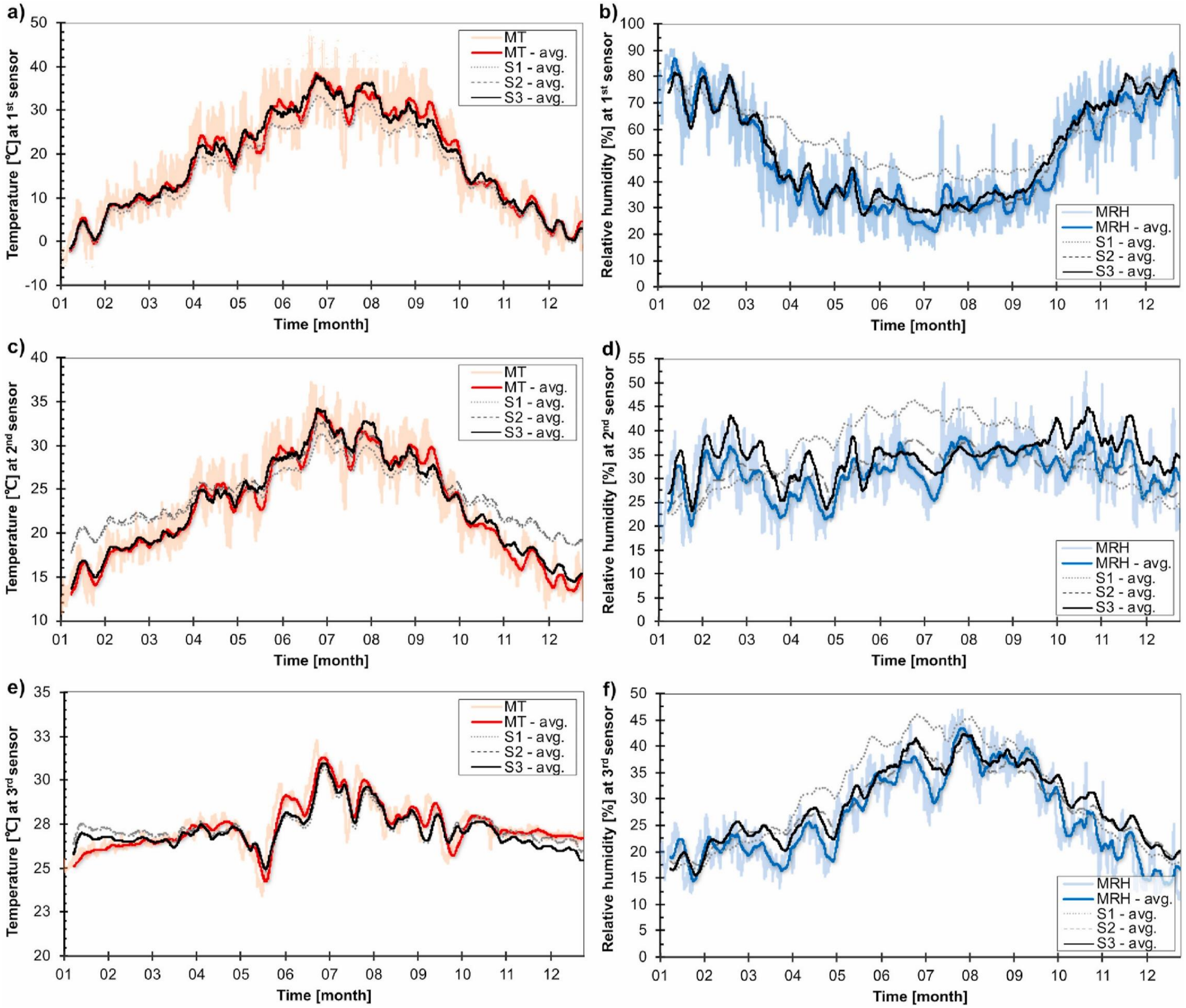


Table. 1 Monthly transient U-values [W/(m²K)] according to dynamic simulations

Month	*S1*	*S2*	*S3*
October	0.137	0.118	0.181
November	0.155	0.148	0.217
December	0.157	0.154	0.222
January	0.150	0.148	0.215
February	0.147	0.137	0.207
March	0.137	0.131	0.188
April	0.107	0.086	0.123

WUFI (Heat and Moisture) model:

- Boundary Conditions according to monitoring measurements
- 3 different, advancing mondels:
  - S1: standard model with general material properties from manufacturer
  - S2: adding air change and radiation in the cavity
  - S3: adding the laboratory measured material properties

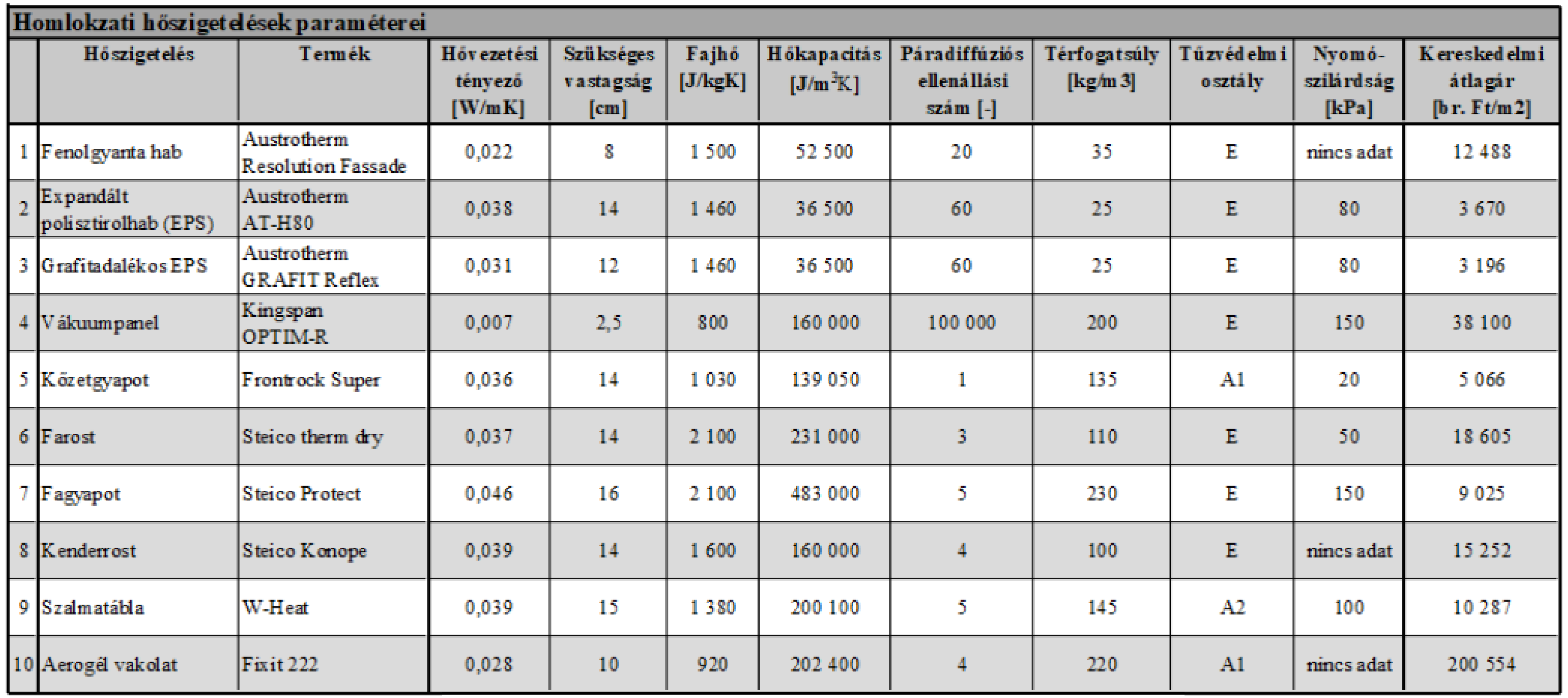
Conclusion:

- Blowing with 10-12 kg/m³ bulk density instead of 15 kg/m³ results in 35% higher U value of the construction!!!

https://doi.org/10.1016/j.csite.2021.100941
https://doi.org/10.2478/9788395669699-032

Technical value analysis

COMBINEX method with Guilford weighting



Homlokzati hőszigetelések paraméterei

	Hőszigetelés	Termék	Hővezetési tényező [W/mK]	Szükséges vastagság [cm]	Fajhő [J/kgK]	Hőkapacitás [J/m^{3}K]	Páradiffúziós ellenállási szám [-]	Térfogatsúly [kg/m 3]	Tűzvédelmi osztály	Nyomó-szilárdság [kPa]	Kereskedelmi átlagár [br. Ft/m2]
1	Fenolgyanta hab	Austrotherm Resolution Fassade	0,022	8	1 500	52 500	20	35	E	nincs adat	12 488
2	Expandált polisztirolhab (EPS)	Austrotherm AT-H80	0,038	14	1 460	36 500	60	25	E	80	3 670
3	Grafitadalékos EPS	Austrotherm GRAFIT Reflex	0,031	12	1 460	36 500	60	25	E	80	3 196
4	Vákuumpanel	Kingspan OPTIM-R	0,007	2,5	800	160 000	100 000	200	E	150	38 100
5	Kőzetgyapot	Frontrock Super	0,036	14	1 030	139 050	1	135	A1	20	5 066
6	Farost	Steico therm dry	0,037	14	2 100	231 000	3	110	E	50	18 605
7	Fagyapot	Steico Protect	0,046	16	2 100	483 000	5	230	E	150	9 025
8	Kenderrost	Steico Konope	0,039	14	1 600	160 000	4	100	E	nincs adat	15 252
9	Szalmatábla	W-Heat	0,039	15	1 380	200 100	5	145	A2	100	10 287
10	Aerogél vakolat	Fixit 222	0,028	10	920	202 400	4	220	A1	nincs adat	200 554

- Thermal conductivity
- Volumetric heat capacity
- Vapour diffusion resistance factor
- Fire resistance
- Compression strength
- Price
- Global warming potential
- Workability
- Etc.

1) Select and collect comparable material and technical parameters of natural, bio-based or conventional thermal insulation materials.

https://tdk.bme.hu/EMK/ep2/Tarsashazak-innovativ-energiahatekonysagi

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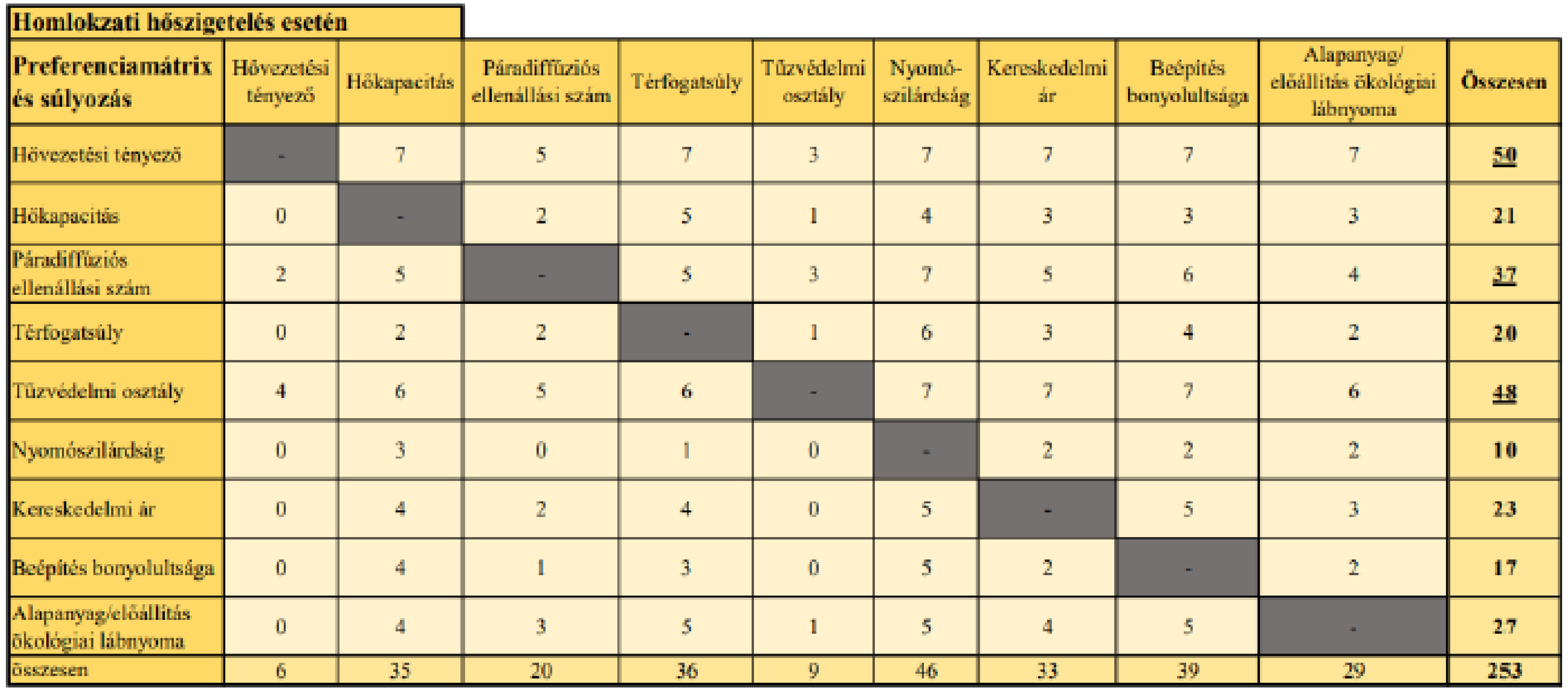
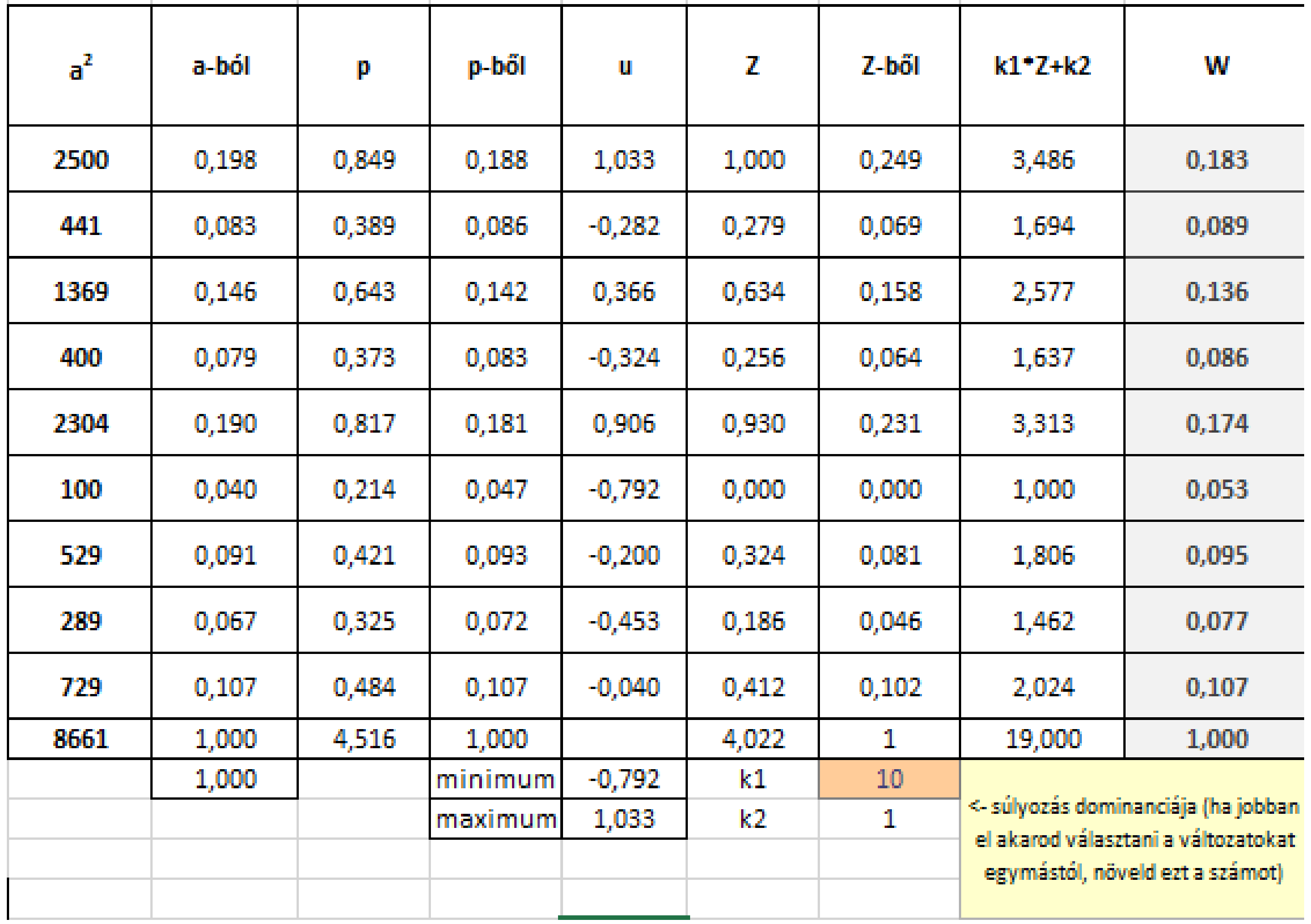
Technical value analysis



Homlokzati hőszigetelés esetén

Preferenciamátrix és súlyozás	Hővezetési tényező	Hőkapacitás	Páradiffúziós ellenállási szám	Térfogatsúly	Tűzvédelmi osztály	Nyomó-szilárdság	Kereskedelmi ár	Beépítés bonyolultsága	Alapanyag/ előállítás ökológiai lábnyoma	**Összesen**
Hővezetési tényező	-	7	5	7	3	7	7	7	7	**50**
Hőkapacitás	0	-	2	5	1	4	3	3	3	**21**
Páradiffúziós ellenállási szám	2	5	-	5	3	7	5	6	4	**37**
Térfogatsúly	0	2	2	-	1	6	3	4	2	**20**
Tűzvédelmi osztály	4	6	5	6	-	7	7	7	6	**48**
Nyomószilárdság	0	3	0	1	0	-	2	2	2	**10**
Kereskedelmi ár	0	4	2	4	0	5	-	5	3	**23**
Beépítés bonyolultsága	0	4	1	3	0	5	2	-	2	**17**
Alapanyag/előállítás ökológiai lábnyoma	0	4	3	5	1	5	4	5	-	**27**
összesen	6	35	20	36	9	46	33	39	29	**253**

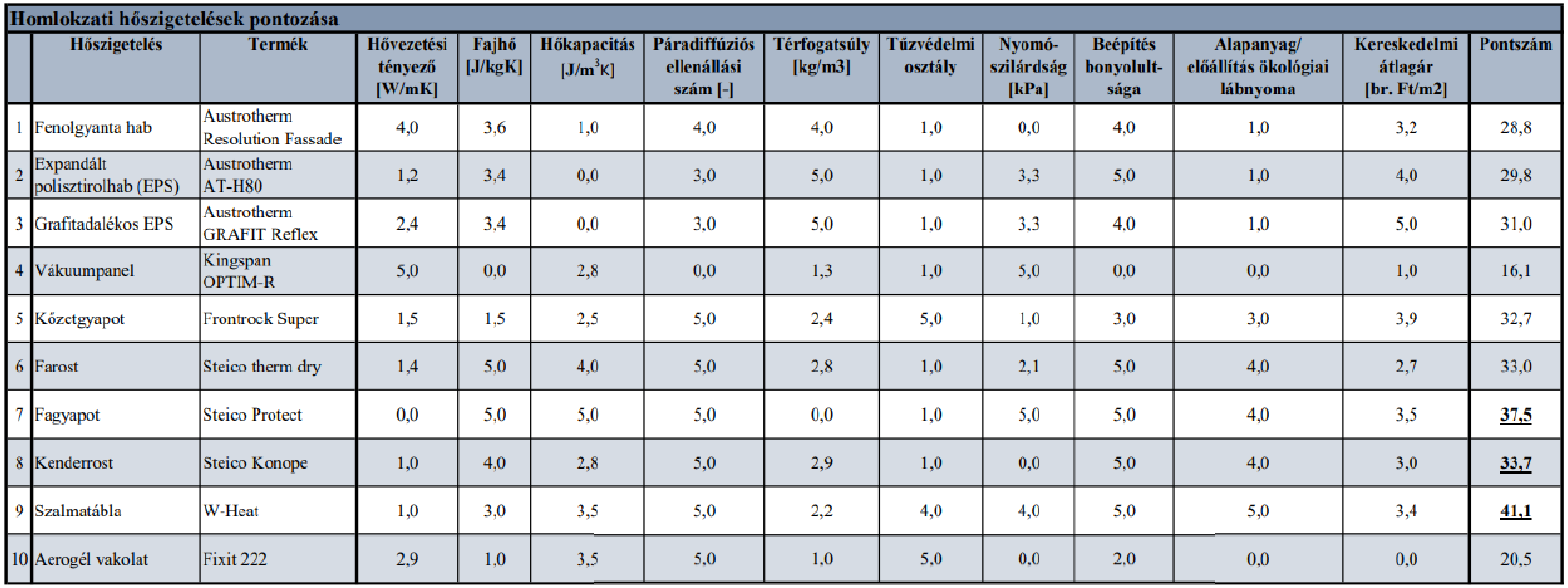


a^2	a-ból	p	p-ből	u	Z	Z-ből	k1*Z+k2	W
2500	0,198	0,849	0,188	1,033	1,000	0,249	3,486	0,183
441	0,083	0,389	0,086	-0,282	0,279	0,069	1,694	0,089
1369	0,146	0,643	0,142	0,366	0,634	0,158	2,577	0,136
400	0,079	0,373	0,083	-0,324	0,256	0,064	1,637	0,086
2304	0,190	0,817	0,181	0,906	0,930	0,231	3,313	0,174
100	0,040	0,214	0,047	-0,792	0,000	0,000	1,000	0,053
529	0,091	0,421	0,093	-0,200	0,324	0,081	1,806	0,095
289	0,067	0,325	0,072	-0,453	0,186	0,046	1,462	0,077
729	0,107	0,484	0,107	-0,040	0,412	0,102	2,024	0,107
8661	1,000	4,516	1,000		4,022	1	19,000	1,000
	1,000		minimum	-0,792	k1	10	<- súlyozás dominanciája (ha jobban el akarod választani a változatokat egymástól, növeld ezt a számot)	
			maximum	1,033	k2	1		

2) Create an online poll about the comparison criteria, use pair comparison
3) Compose the preference matrix from the results of the polling
4) Calculate the weights according to Guilford

https://tdk.bme.hu/EMK/ep2/Tarsashazak-innovativ-energiahatekonysagi

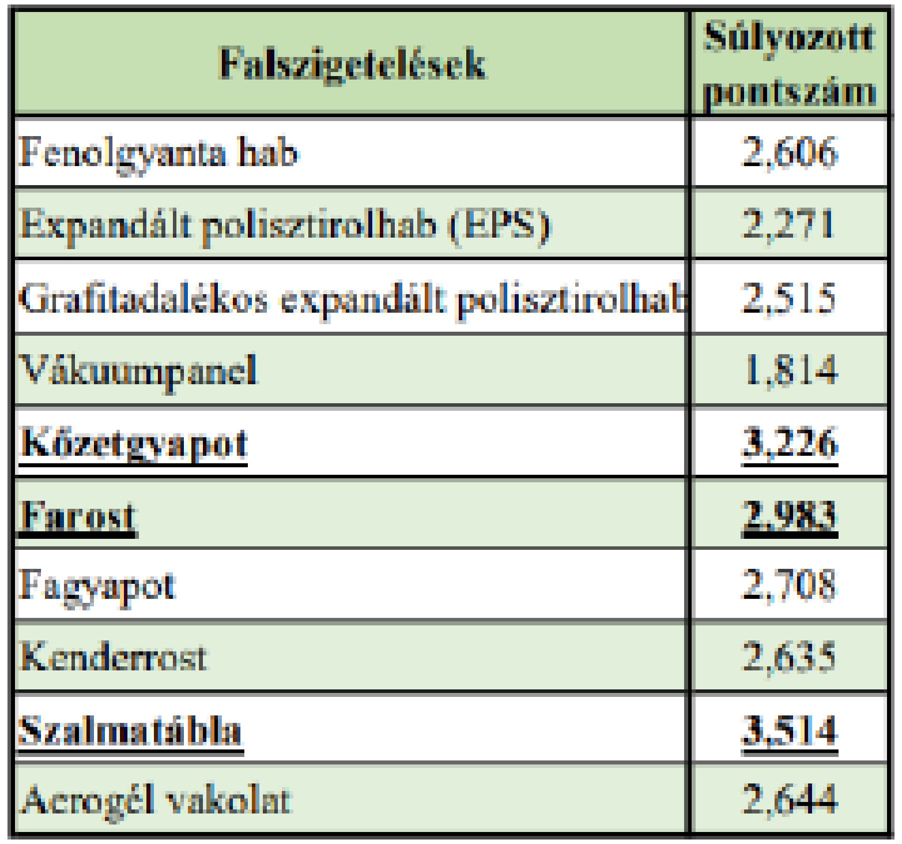
Technical value analysis



Homlokzati hőszigetelések pontozása

	Hőszigetelés	Termék	Hővezetési tényező [W/mK]	Fajhő [J/kgK]	Hőkapacitás $[J/m^3K]$	Páradiffúziós ellenállási szám [-]	Térfogatsúly [kg/m3]	Tűzvédelmi osztály	Nyomó-szilárdság [kPa]	Beépítés bonyolult-sága	Alapanyag/ előállítás ökológiai lábnyoma	Kereskedelmi átlagár [br. Ft/m2]	Pontszám
1	Fenolgyanta hab	Austrotherm Resolution Fassade	4,0	3,6	1,0	4,0	4,0	1,0	0,0	4,0	1,0	3,2	28,8
2	Expandált polisztirolhab (EPS)	Austrotherm AT-H80	1,2	3,4	0,0	3,0	5,0	1,0	3,3	5,0	1,0	4,0	29,8
3	Grafitadalékos EPS	Austrotherm GRAFIT Reflex	2,4	3,4	0,0	3,0	5,0	1,0	3,3	4,0	1,0	5,0	31,0
4	Vákuumpanel	Kingspan OPTIM-R	5,0	0,0	2,8	0,0	1,3	1,0	5,0	0,0	0,0	1,0	16,1
5	Kőzetgyapot	Frontrock Super	1,5	1,5	2,5	5,0	2,4	5,0	1,0	3,0	3,0	3,9	32,7
6	Farost	Steico therm dry	1,4	5,0	4,0	5,0	2,8	1,0	2,1	5,0	4,0	2,7	33,0
7	Fagyapot	Steico Protect	0,0	5,0	5,0	5,0	0,0	1,0	5,0	5,0	4,0	3,5	**37,5**
8	Kenderrost	Steico Konope	1,0	4,0	2,8	5,0	2,9	1,0	0,0	5,0	4,0	3,0	**33,7**
9	Szalmatábla	W-Heat	1,0	3,0	3,5	5,0	2,2	4,0	4,0	5,0	5,0	3,4	**41,1**
10	Aerogél vakolat	Fixit 222	2,9	1,0	3,5	5,0	1,0	5,0	0,0	2,0	0,0	0,0	20,5

Results with weights:



Falszigetelések	Súlyozott pontszám
Fenolgyanta hab	2,606
Expandált polisztirolhab (EPS)	2,271
Grafitadalékos expandált polisztirolhab	2,515
Vákuumpanel	1,814
Kőzetgyapot	**3,226**
Farost	**2,983**
Fagyapot	2,708
Kenderrost	2,635
Szalmatábla	**3,514**
Aerogél vakolat	2,644

5) Scoring relative to comparison (e.g. 1-5 scale based on performance)
6) Weight the scores and get the final result

https://tdk.bme.hu/EMK/ep2/Tarsashazak-innovativ-energiahatekonysagi

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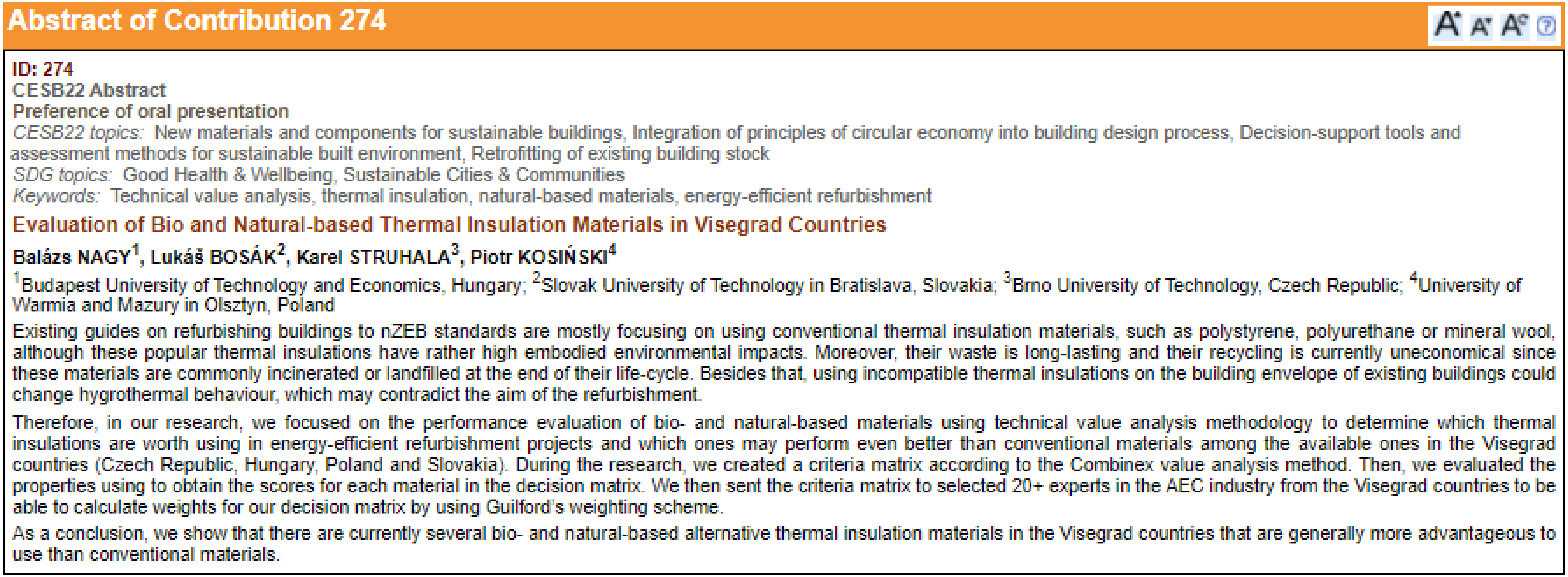

Abstract of Contribution 274

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CESB22 Abstract
Preference of oral presentation
CESB22 topics: New materials and components for sustainable buildings, Integration of principles of circular economy into building design process, Decision-support tools and assessment methods for sustainable built environment, Retrofitting of existing building stock
SDG topics: Good Health & Wellbeing, Sustainable Cities & Communities
Keywords: Technical value analysis, thermal insulation, natural-based materials, energy-efficient refurbishment

Evaluation of Bio and Natural-based Thermal Insulation Materials in Visegrad Countries

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Existing guides on refurbishing buildings to nZEB standards are mostly focusing on using conventional thermal insulation materials, such as polystyrene, polyurethane or mineral wool, although these popular thermal insulations have rather high embodied environmental impacts. Moreover, their waste is long-lasting and their recycling is currently uneconomical since these materials are commonly incinerated or landfilled at the end of their life-cycle. Besides that, using incompatible thermal insulations on the building envelope of existing buildings could change hygrothermal behaviour, which may contradict the aim of the refurbishment.

Therefore, in our research, we focused on the performance evaluation of bio- and natural-based materials using technical value analysis methodology to determine which thermal insulations are worth using in energy-efficient refurbishment projects and which ones may perform even better than conventional materials among the available ones in the Visegrad countries (Czech Republic, Hungary, Poland and Slovakia). During the research, we created a criteria matrix according to the Combinex value analysis method. Then, we evaluated the properties using to obtain the scores for each material in the decision matrix. We then sent the criteria matrix to selected 20+ experts in the AEC industry from the Visegrad countries to be able to calculate weights for our decision matrix by using Guilford's weighting scheme.

As a conclusion, we show that there are currently several bio- and natural-based alternative thermal insulation materials in the Visegrad countries that are generally more advantageous to use than conventional materials.

THANK YOU FOR YOUR ATTENTION!

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