

Higher Thermal Class Conductor Insulation Paper

Protect Your Power Transformer
from Overload Conditions and
Extend Asset Life



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HOW TO ASK A QUESTION



Click the question mark icon in the top right panel.

A dark interface for asking a question. It features a text input field with the placeholder "Enter your question", a "Send" button, and a note: "Your question will be sent to staff".

Type your question. This will only be seen by the event organizers.



WEIDMANN

130 °C CONDUCTOR INSULATION PAPER FOR POWER TRANSFORMERS

19.03.2026



130 °C CONDUCTOR INSULATION PAPER FOR POWER TRANSFORMERS

01

Theoretical Overview, Overloading, and
Transformer Temperature Limits

02

Development and Validation

03

Discussion

REQUIREMENTS FOR POWER TRANSFORMER SOLID INSULATION

OVERVIEW AND FUNCTIONS

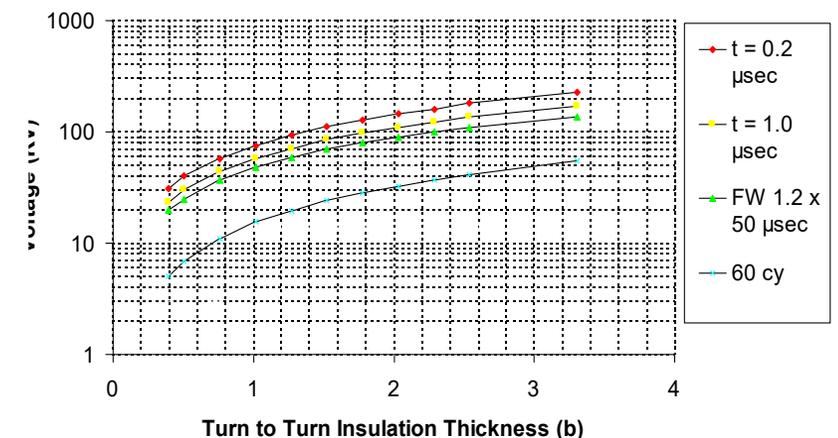
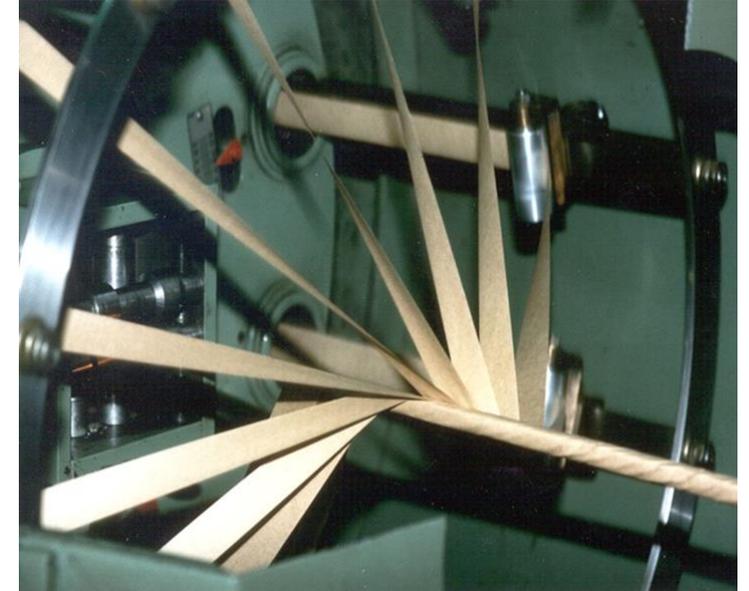
- Transformer solid insulation largely defines the major transformer characteristics:
 - Size, weight, footprint, and cost
 - Losses and efficiency
 - Long-term reliability and resilience
- Functions of solid insulation:
 - Electrical Insulation
 - Dielectric liquids are five times better insulator compared to air
 - Dried and liquid impregnated paper is an excellent insulator
 - Mechanical Support
 - Cellulose is strong insulation
 - Pressboard has good mechanical stability
 - Heat Transfer
 - Paper and pressboard are porous... liquid can flow through material
 - Dielectric liquid is good for heat transfer – used to remove heat from windings



CONDUCTOR WRAP INSULATION PAPER FOR POWER TRANSFORMERS

PURPOSE, TYPES, AND DESIGN CONSIDERATIONS

- Purpose:
 - Insulation applied to cover conductor wires to prevent current (electrical discharge) from flowing
- Types:
 - Calendered crepe papers
 - Weidmann 22HCC
 - High strength, flexibility, and resilience during coil winding
 - Flat papers
- Design considerations:
 - Total thickness of conductor wrap insulation paper layers is based on turn-to-turn voltage in windings
 - Using calendered crepe papers can wrap tightly
 - Temperature limits – defined by standards, based on thermal class



TEMPERATURE LIMITS FOR CONDUCTOR WRAP PAPER AFFECTED BY TRANSFORMER LOADING

- Normal load conditions = low temperatures
 - Normal loading temperature limits from loading guides apply
 - Higher temperature capable insulation materials not required
- Overload conditions = higher losses = higher temperatures
 - Regular or sustained overloads and higher temperatures degrade the life of conventional insulation
 - Standards set temperature limits to avoid significant loss of life
 - Specific standards cover both conventional insulation and higher temperature capable insulation
- Higher temperature capable insulation materials allow:
 - Lower loss of life during overloads, or
 - Higher overload temperatures with same loss of life
 - Fewer transformers needed on the grid for N-1 reasons
 - Increasing short-time overload limits for transformers will free up capacity for new load and generation, reduce the need for reinvestments, and provide back-up capacity in case of emergency

IEC 60076 PART 14 – STD FOR LIQUID-IMMERSED POWER TRANSFORMERS USING HIGH-TEMPERATURE INSULATION MATERIALS

- Conventional insulation system
= Kraft paper and mineral oil
- Semi-hybrid winding (120 °C)
= Thermally Upgraded Kraft (TUK) paper and mineral oil
- Semi-hybrid winding (130 °C)
= **New Weidmann Higher Thermal Class Conductor Insulation Paper** and mineral oil
 - No high-temperature spacer material required
- Equivalent IEEE Standard = IEEE C57.154

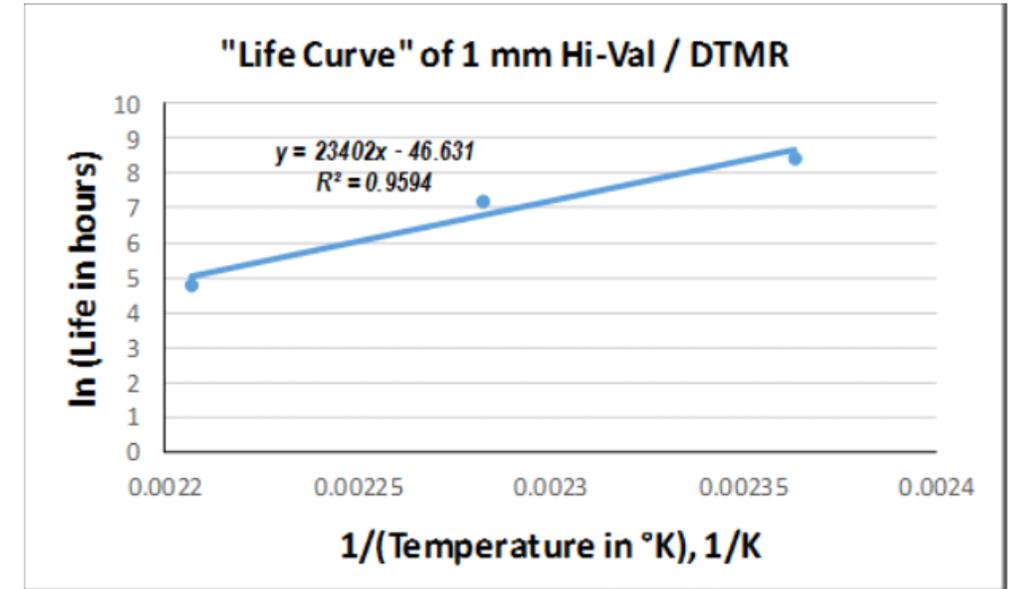
Table 2 – Winding/system insulation comparison

		Conventional insulation system	Hybrid insulation systems			High-temperature insulation system ^b
			Semi-hybrid winding	Mixed hybrid winding	Full hybrid winding	
Type of insulating component ^a	Liquid	C or H	C or H	C or H	C or H	H
	Conductor insulation	C	H	C and H combination	H	H
	Conventional (C) or high-temperature (H)					
	Spacers/strips	C	C	C and H combination	H	H
	Barrier solid	C	C	C	C	H
Insulating component application temperature	Top liquid rise	C	C	C	C	H
	Average winding rise	C	H	C	H	H
	Conventional (C) or high-temperature (H)					
	Hot-spot winding rise	C	H	H	H	H
a Only basic transformer parts are shown and the temperature of other parts will depend on the results of the thermal mapping.						
b Since thermal gradients exist in all transformers, some conventional insulation is acceptable in locations where conventional temperatures are maintained.						

THERMAL CLASS OF TRANSFORMERBOARD IN MINERAL OIL

SPECIAL ACCELERATED AGING TEST

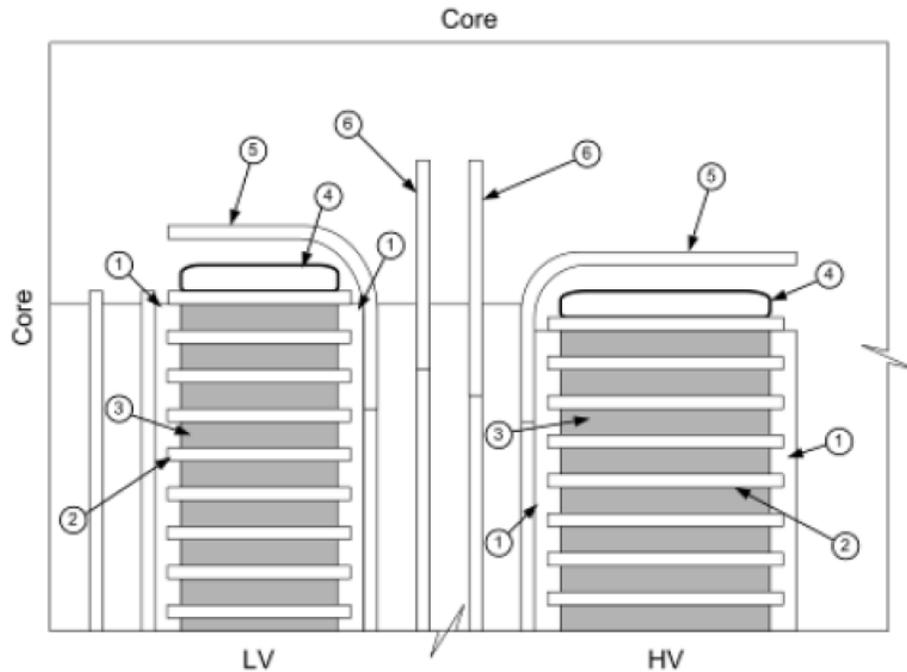
- Method 1 – IEEE C57.100-2011
 - TUK is considered the IPS (TSR and DPv at end-of-life)
 - TB (LD and HD) is considered the candidate system
- Method 2 – IEEE C57.100-1999, TSR
 - All materials (TUK and TB) are evaluated with a criteria of 50% TSR at 65,000 hours
- Method 3 – IEEE C57.100-1999, DPv
 - All materials (TUK and TB) are evaluated with a criteria of 200 DPv at 150,000 hours
- **The results confirmed that Transformerboard’s thermal class is, at least, 120 °C**
- This validates an empirically based application of this material as a part of the 120 °C class insulation system in both power and distribution transformers



Thermal Index Results (°C)				
Test	Material	Method 1	Method 2	Method 3
DTMR	1 mm Hi-Val	125.3	127.3	115.4
	0.13 mm TUK	-	123.8	116.7
PTMR	2 mm T4	129.4	116.2	113.0
	0.08 mm TUK	-	110.8	105.0

“Experimental Study of Sealed Tube Accelerated Aging Test Parameters and Determination of the Thermal Class of Transformerboard,” A. Levin, K. M. Biggie, L. Dreier, B. A. Greaves, T. A. Prevost and D. J. Tschudi, in IEEE Transactions on Dielectrics and Electrical Insulation, vol. 29, no. 5, pp. 1958-1965, Oct. 2022, doi: 10.1109/TDEI.2022.3189324

SEMI-HYBRID WINDING = MIXED OR FULL HYBRID WINDING USING NEW WEIDMANN HIGHER THERMAL CLASS CONDUCTOR INSULATION PAPER



- Key**
- LV low voltage
 - HV high voltage
 - 1 conventional axial spacers against the winding
 - 2 conventional radial spacers
 - 3 high-temperature conductor insulation
 - 4 conventional static rings
 - 5 conventional angle rings
 - 6 conventional barriers

Figure 1 – Example of semi-hybrid insulation windings

Table 5 – Suggested maximum overload temperature limits for transformers with hybrid insulation systems

	Conventional insulation system ^a	Hybrid insulation system				
		Semi-hybrid insulation winding	Mixed hybrid insulation winding	Full hybrid insulation winding ^b		
Minimum required solid high-temperature insulation thermal class	105	120	130	130	140	155
Top liquid temperature with normal cyclic loading (°C)	105	105	105	105	105	105
Top liquid temperature with long-time emergency loading (°C)	115	115	115	115	115	115
Top liquid temperature with short-time emergency loading (°C)	115	115	115	115	115	115
Insulation hot-spot temperature with normal cyclic loading (°C)	120	130	140	140	150	165
Insulation hot-spot temperature with long-time emergency loading (°C)	140	140	150	150	160	175
Insulation hot-spot temperature with short-time emergency loading (°C)	160	160	170	170	180	195

^a Conventional insulation system included only for reference purposes. Refer to IEC 60076-7 for additional information.

^b Essentially oxygen-free applications where the liquid preservation system effectively prevents the ingress of air into the tank.

TRANSFORMER EFFICIENCY

LIMITS TRANSFORMER DESIGN

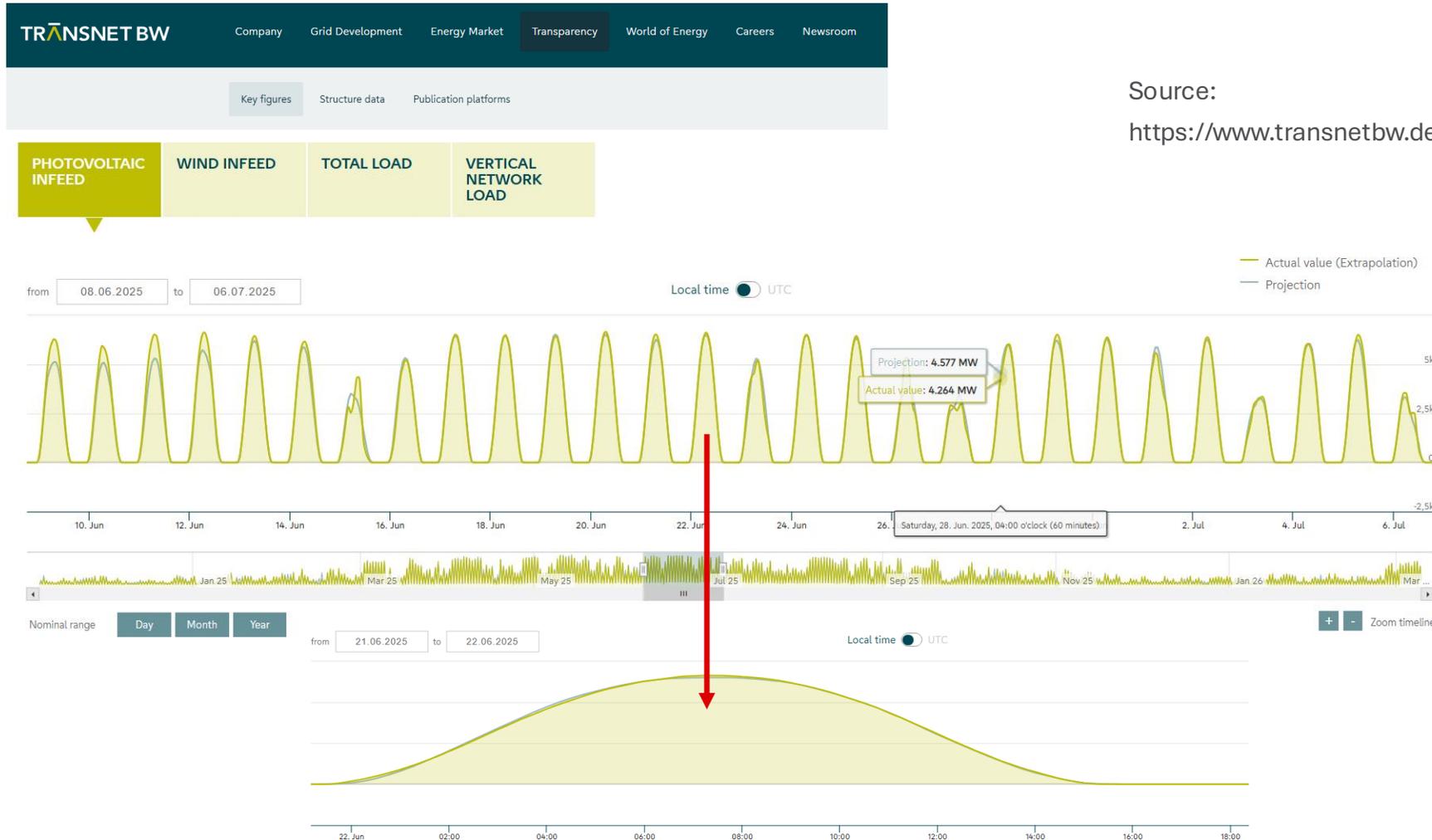
- Transformers are limited to peak efficiency levels, and therefore losses, e.g., given by EU Ecodesign Tier 2 regulations or other efficiency standards
- During overload conditions, efficiency standards are not valid anymore

$$PEI = 1 - \frac{2(P_0 + P_{c0} + P_{ck}(k_{PEI}))}{S_r \sqrt{\frac{P_0 + P_{c0} + P_{ck}(k_{PEI})}{P_k}}} = 1 - \frac{2}{S_r} \sqrt{(P_0 + P_{c0} + P_{ck}(k_{PEI}))P_k} \quad (\%)$$

P_0	is the no load losses measured at rated voltage and rated frequency on the rated tap
P_{c0}	is the electrical power required by the cooling system for no load operation, derived from the type test measurements of the power taken by the fan and liquid pump motors (for ONAN and ONAN/ONAF cooling systems P_{c0} is always zero)
$P_{ck}(k_{PEI})$	is the electrical power required by the cooling system in addition to P_{c0} to operate at k_{PEI} times the rated load. P_{ck} is a function of the load. $P_{ck}(k_{PEI})$ is derived from the type test measurements of the power taken by the fan and liquid pump motors (for ONAN cooling systems P_{ck} is always zero).
P_k	is the measured load loss at rated current and rated frequency on the rated tap corrected to the reference temperature
S_r	is the rated power of the transformer or autotransformer on which P_k is based
k_{PEI}	is the load factor at which Peak Efficiency Index occurs;

EXAMPLE OF OVERLOADING

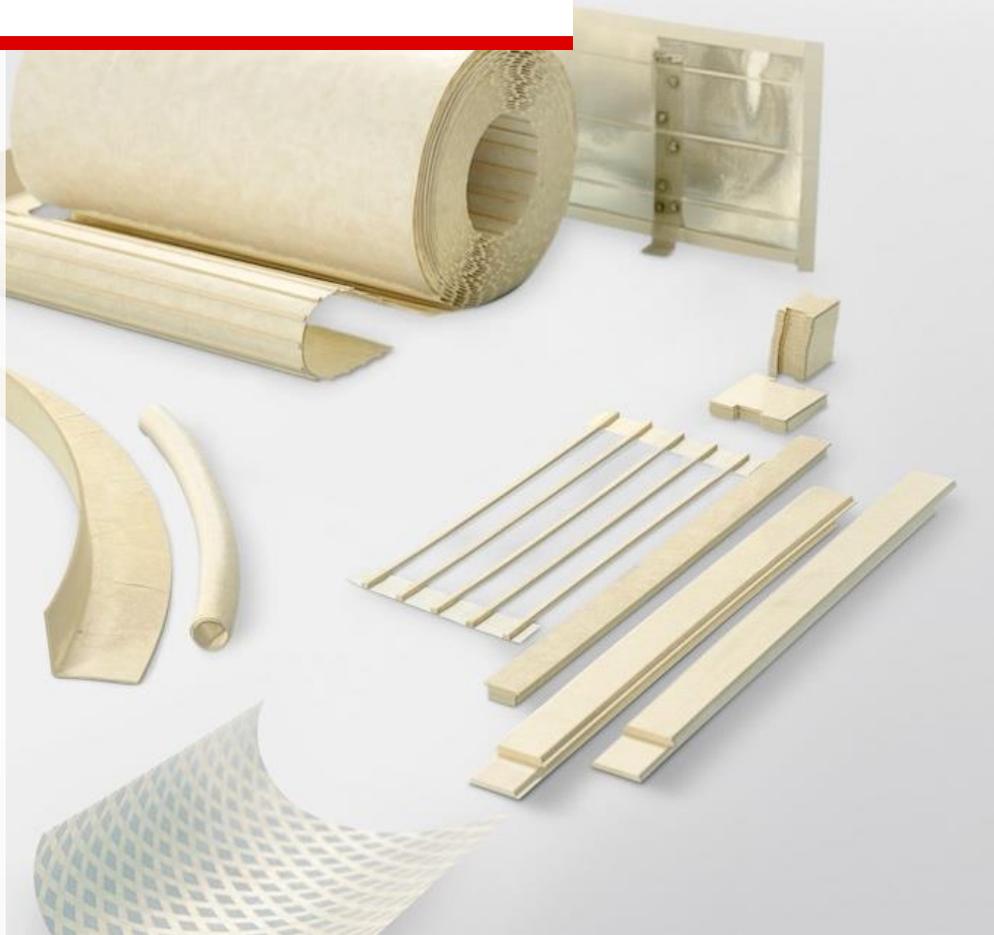
DAILY PHOTOVOLTAIC FEED ON THE GRID



Source:

<https://www.transnetbw.de/en/transparency/market-data/key-figures>

CURRENT HIGH TEMPERATURE SOLUTIONS



- Meta-Aramid

- Meta-Aramid – Cellulose hybrid

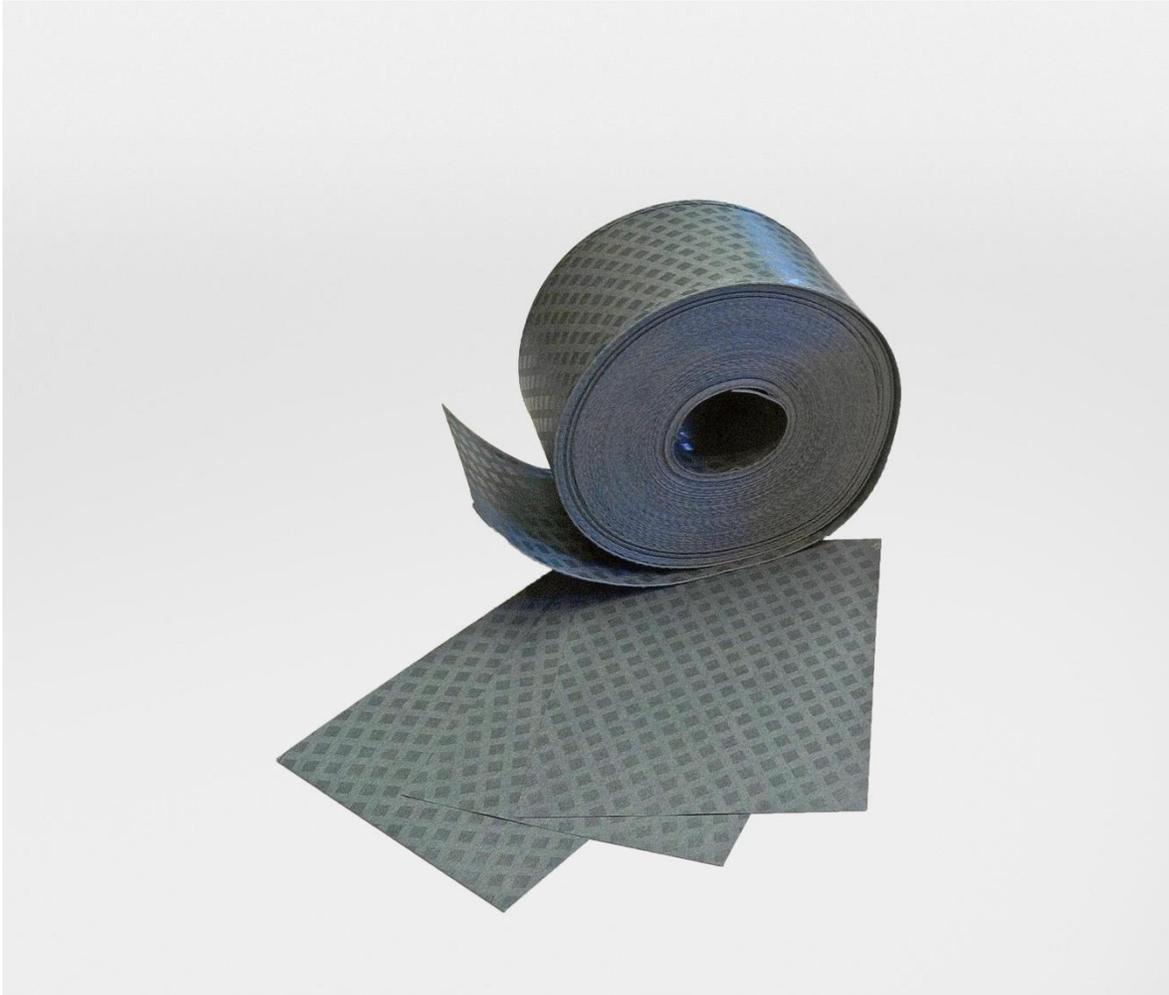
- Mica (typically not for liquid-filled)

- Other organic and/or inorganic material blends (typically not for liquid-filled)

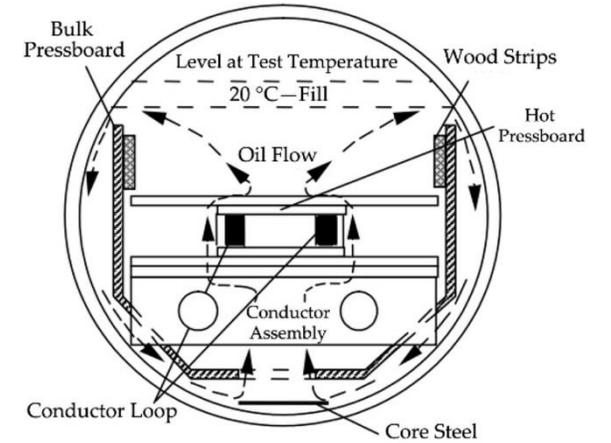
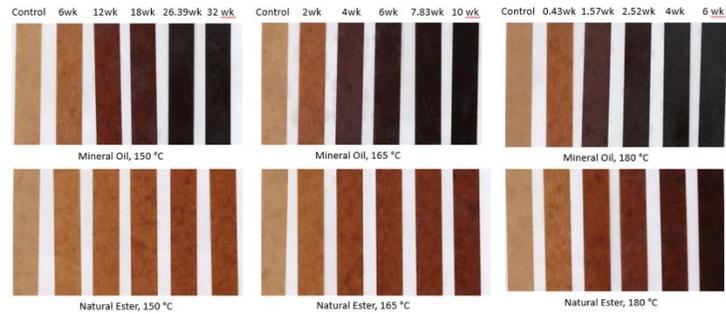
- Weidmann DPE paper for distribution transformers

TRIGGER FOR THE PROJECT

TO DEVELOP A POWER TRANSFORMER CONDUCTOR WRAP PAPER



- DPE as a 130 °C thermal class paper (with mineral oil) for distribution transformers
- Interest from the market for applications in power transformers



EXECUTION OF AGING TESTS

EXECUTION OF AGING TESTS

RESOURCES (TIME, MANPOWER, AND EQUIPMENT)



Temperature	Measuring point (h)				
150 °C	0	1000	2000	3000	4000
165 °C	0	250	500	750	1000
180 °C	0	50	100	200	400

EXECUTION OF AGING TEST

IMPORTANT FACTORS THAT INFLUENCE THE RESULT

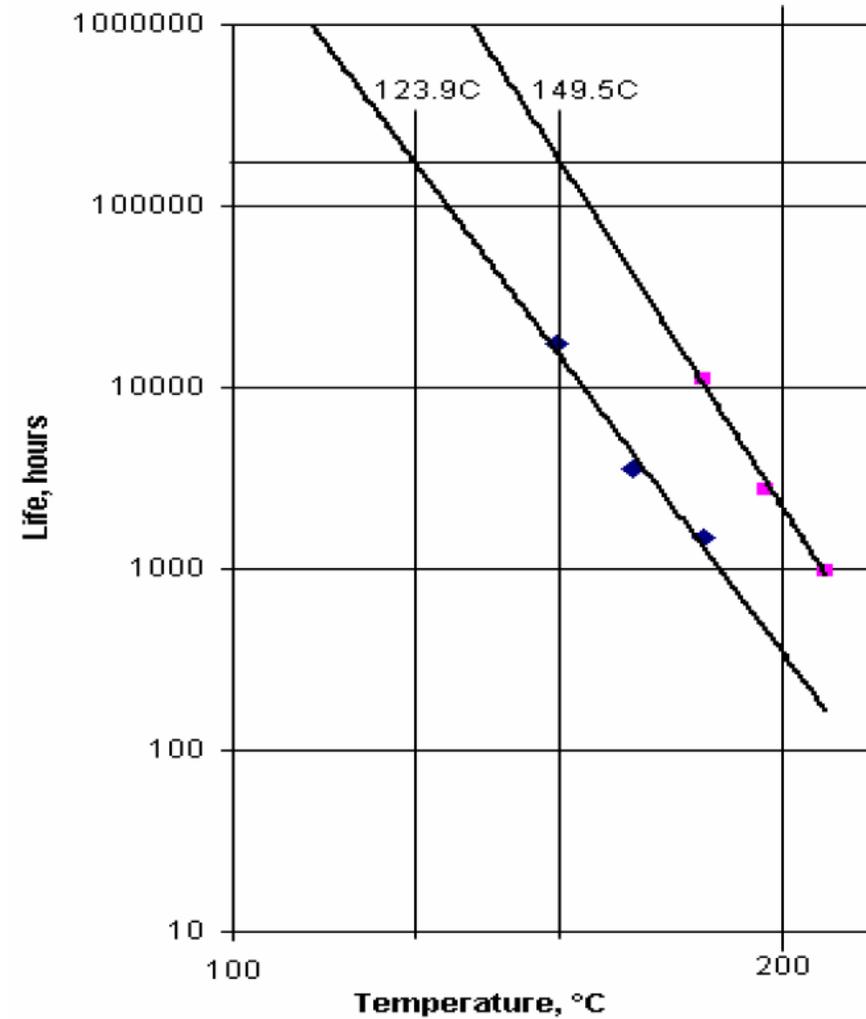
- Aging test vessels
- Temperature(s)
- Evaluated property (DP, tensile strength, elongation, ...)
- Ratio solid to liquid insulation material



EXECUTION OF AGING TEST

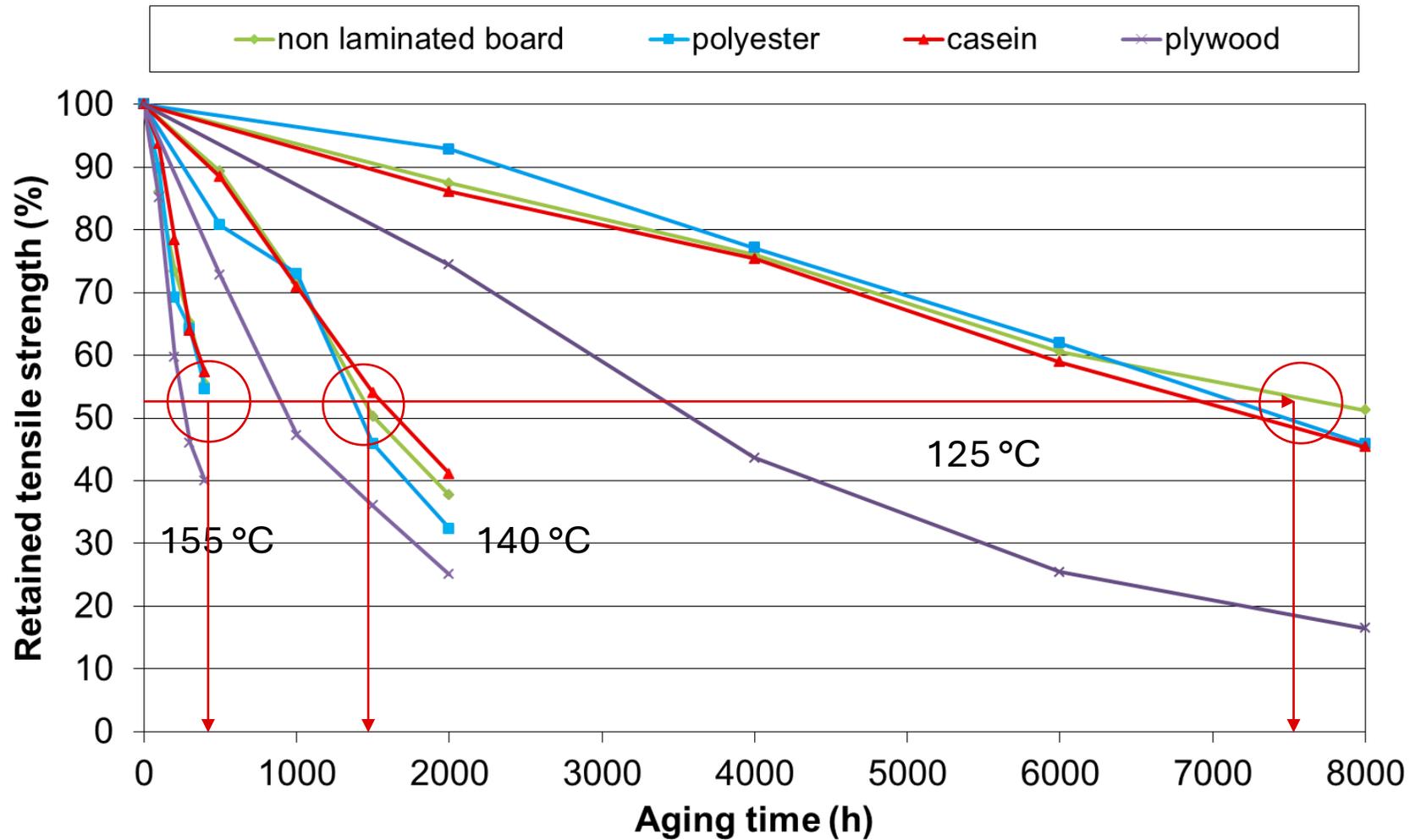
RELATIVE TEMPERATURE INDEX

- Choice of the reference system (industry proven system)
- IEC: Standard Kraft paper
- IEEE: Thermally upgraded paper



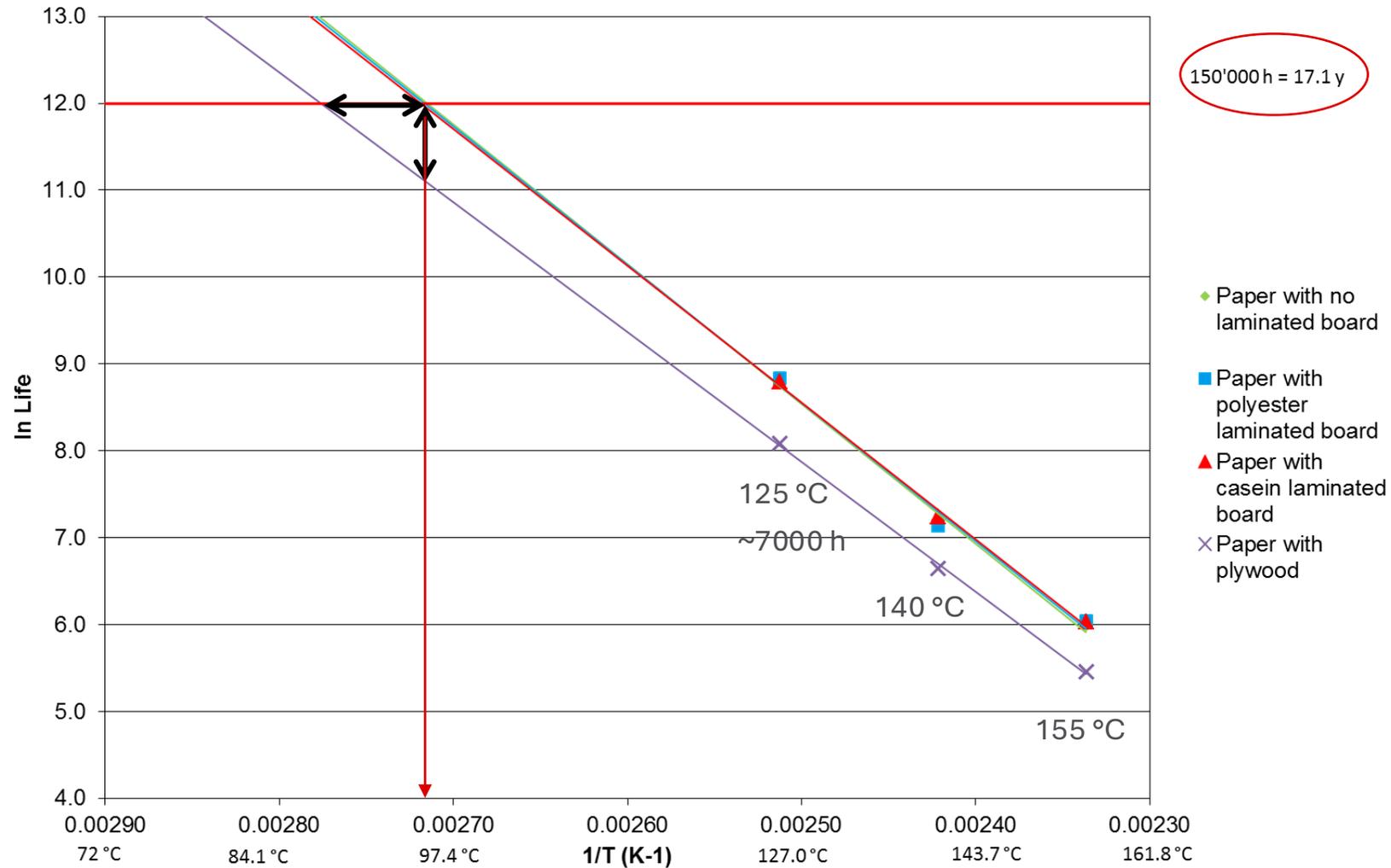
BACKGROUND AGING EXPERIMENTS

ACCELERATED AGING



BACKGROUND AGING EXPERIMENTS

ACCELERATED AGING



GOAL OF THE PROJECT

1

- Thermal class of 130 °C in mineral oil, potentially 140 °C in ester liquids

2

- Same or similar mechanical properties as thermally upgraded kraft paper

3

- Price much more in the range of TUK than aramid

4

- Sustainable cellulose-based material



A row of six light-colored wooden blocks, each with a black letter on its side, spelling out the word "RESULTS". The blocks are arranged on a light-colored wooden surface. In the background, there is a blurred brick wall and a small green plant in a white pot.

R E S U L T S

RESULTS

DPE = HIGHER THERMAL CLASS PAPER

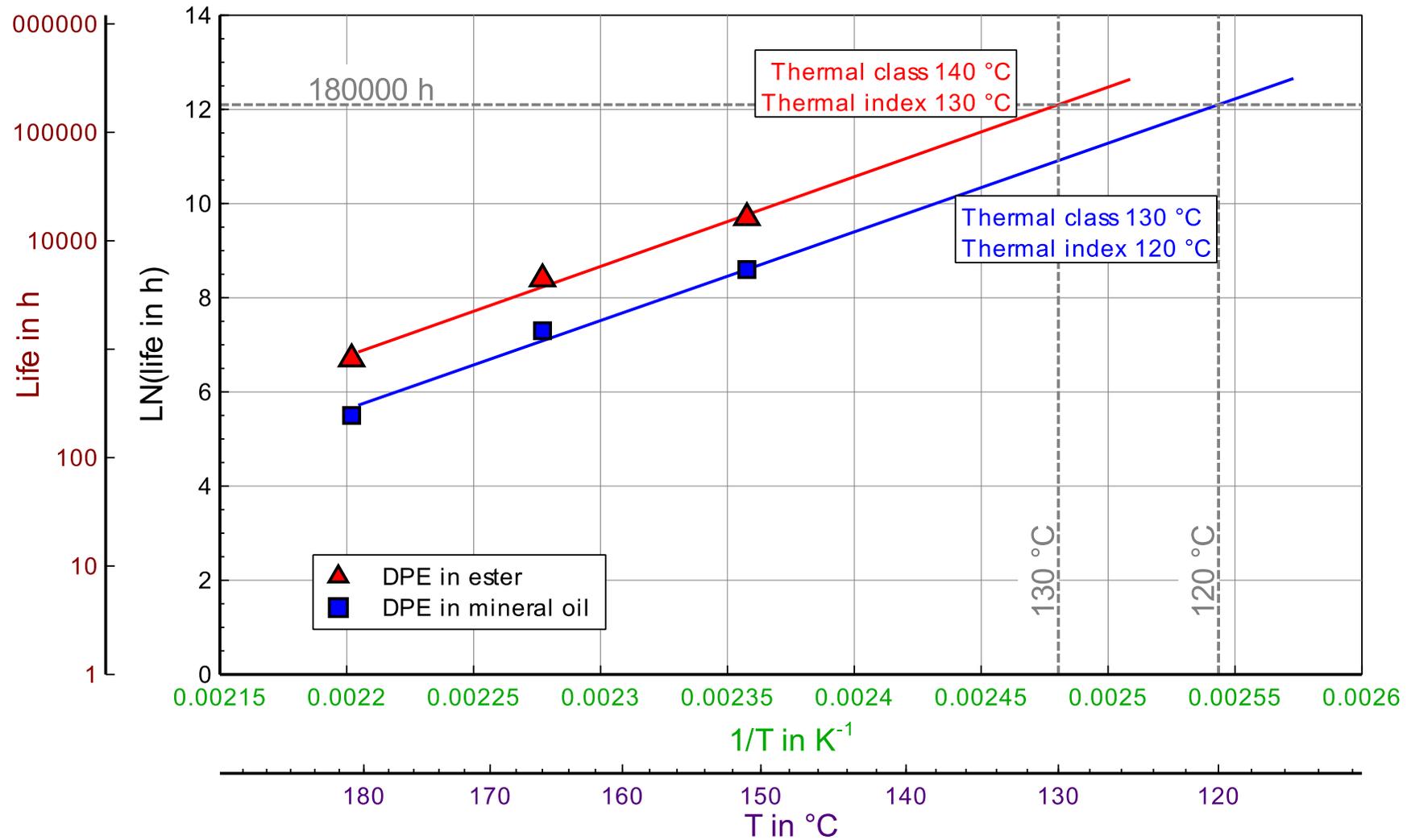
SLOWER AGING, LONGER LIFE

- INSULutions DPE is qualified for the following thermal classes:
 - **130 °C in mineral oil** (10 K higher than thermally upgraded Kraft paper)
 - **140 °C in ester liquid**
- Weidmann completed an extensive series of aging tests per IEEE C57.100™-2011 “Standard Test Procedure for Thermal Evaluation of Insulating Systems for Liquid-Immersed Distribution & Power Transformers”
 - The standard describes an approach for determining the end-of-life criteria of transformer insulating systems, and a procedure to define the insulation system life equation and thermal index, which then relates to the thermal class of the insulation system
 - Aging tests took more than two years to complete



DPE = HIGHER THERMAL CLASS PAPER

AGING TESTS LIFE CURVES IN MINERAL OIL AND ESTER LIQUIDS



DPE = HIGHER THERMAL CLASS PAPER

TRANSFORMER DESIGN TEMPERATURE LIMITS

Limits Based on Standard IEC Terminology

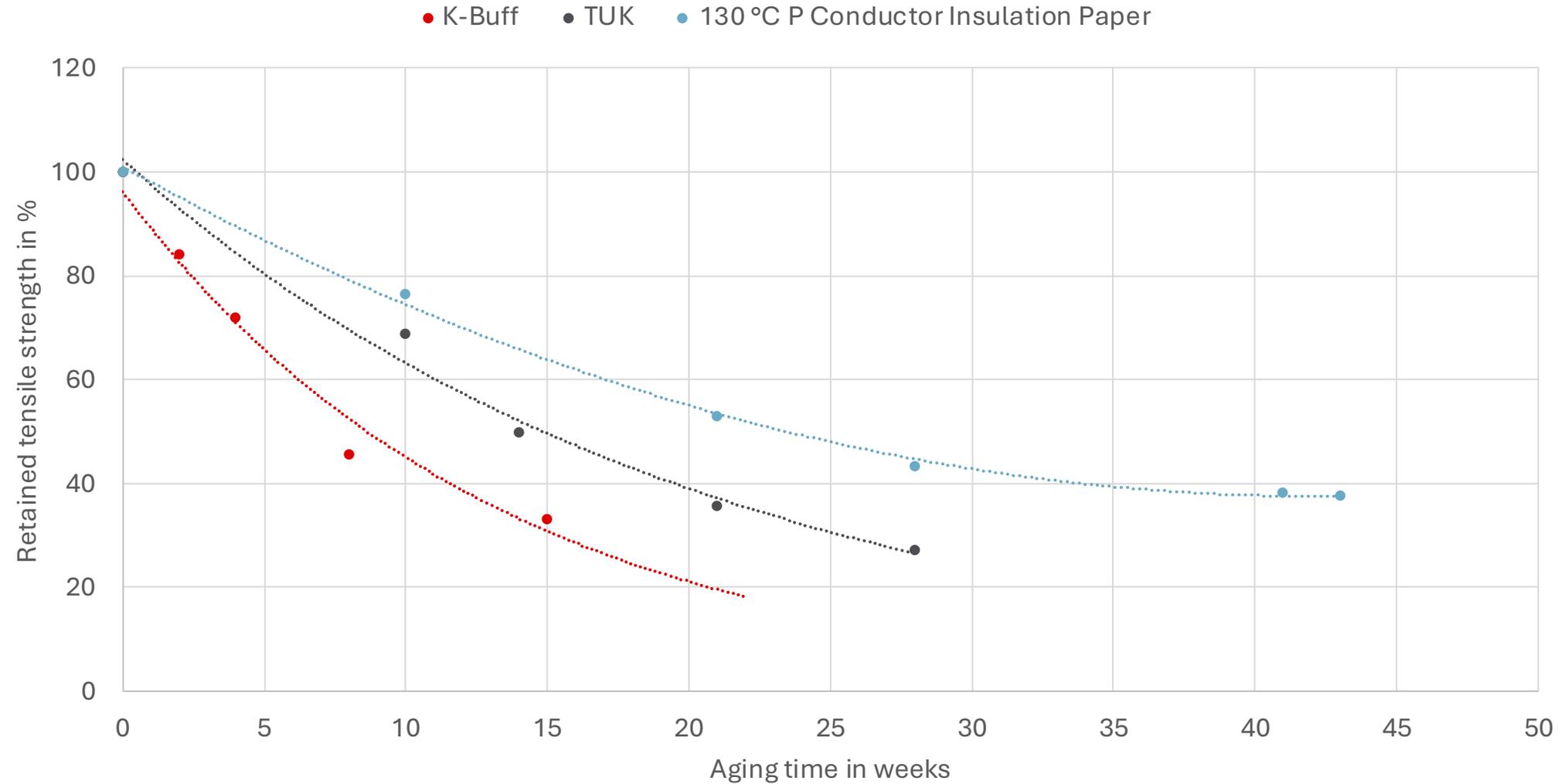
INSULATION SYSTEM	INSULATING MATERIAL AND LIQUID	TRANSFORMER AVERAGE WINDING TEMPERATURE RISE (AWR), K	TRANSFORMER WINDING HOT-SPOT TEMPERATURE RISE, K	SYSTEM THERMAL CLASS, °C
INDUSTRY PROVEN SYSTEM	Kraft in mineral oil	65 / 70	78	105
	TU Kraft in mineral oil	75	90	120
DPE SYSTEM	DPE in mineral oil	85	100	130
	DPE in ester liquid	95	110	140

Limits Based on Standard IEEE Terminology

INSULATION SYSTEM	INSULATING MATERIAL AND LIQUID	TRANSFORMER AVERAGE WINDING TEMPERATURE RISE (AWR), K	TRANSFORMER WINDING HOT-SPOT TEMPERATURE RISE, K	SYSTEM THERMAL CLASS, °C
INDUSTRY PROVEN SYSTEM	Kraft in mineral oil	55	65	105
	TU Kraft in mineral oil	65	80	120
DPE SYSTEM	DPE in mineral oil	75	90	130
	DPE in ester liquid	85	100	140

AGING RESULTS OF 130 °C P CONDUCTOR INSULATION PAPER

AGING IN MINERAL OIL AT 165 °C



NEW WEIDMANN PAPER – SUSTAINABLE SOLUTION

SUSTAINABILITY OVERVIEW

- New paper is engineered using 100% cellulose, giving the following sustainability benefits, compared to synthetic polymer-based higher temperature materials:
 - Derived from renewable (natural plant) sources
 - Fully recyclable (prior to dielectric liquid impregnation)
 - Able to be downcycled as a fuel source at end-of-life (after dielectric liquid impregnation)

Article 5

Ecodesign requirements

1. In order to address environmental impacts and based on the product parameters referred to in Annex I, the ecodesign requirements in the delegated acts adopted pursuant to Article 4 shall be such as to improve the following product aspects ('product aspects') where those product aspects are relevant to the product group concerned:

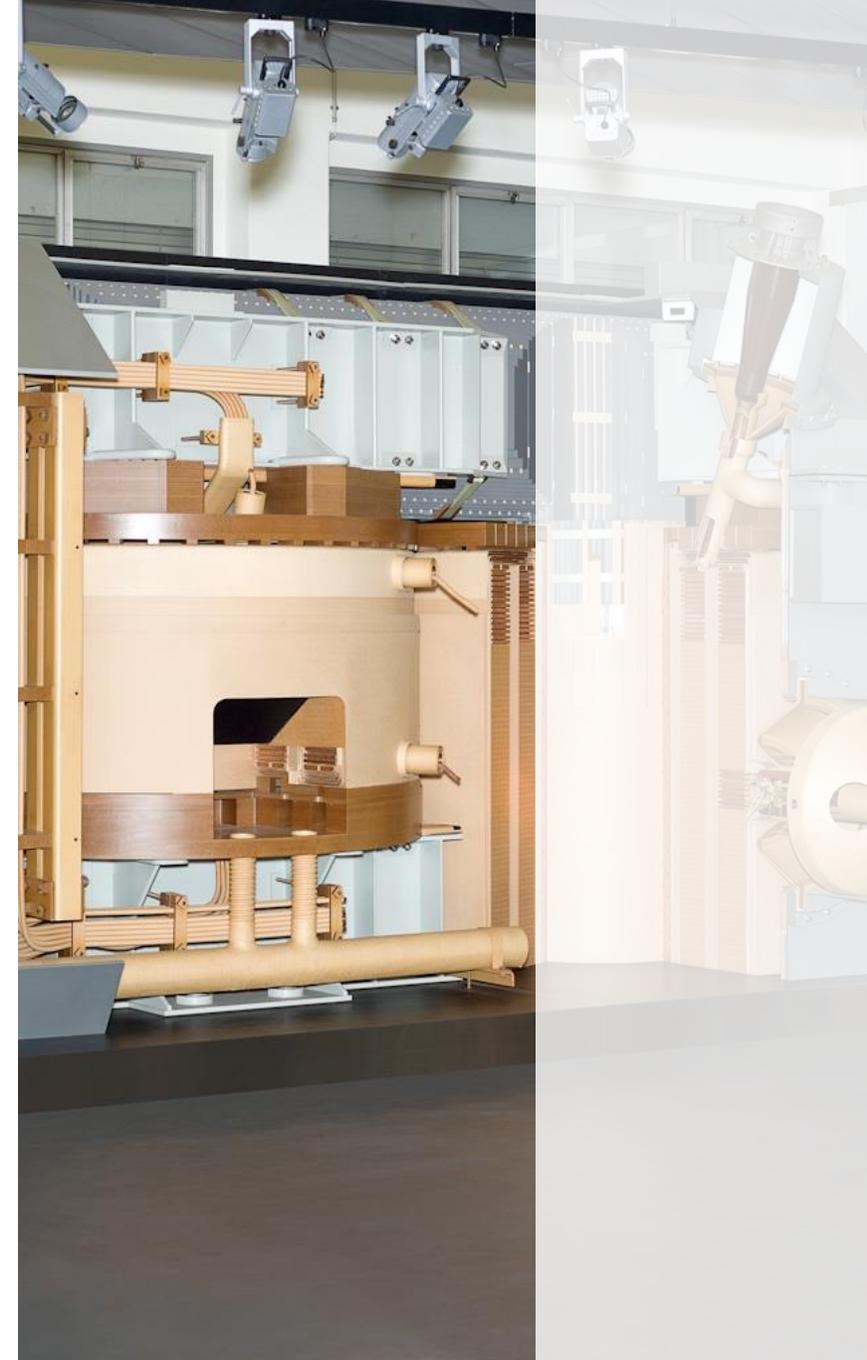
- (a) durability;
- (b) reliability;
- (c) reusability;
- (d) upgradability;
- (e) repairability;
- (f) the possibility of maintenance and refurbishment;
- (g) the presence of substances of concern;
- (h) energy use and energy efficiency;
- (i) water use and water efficiency;
- (j) resource use and resource efficiency;
- (k) recycled content;
- (l) the possibility of remanufacturing;
- (m) recyclability;
- (n) the possibility of the recovery of materials;
- (o) environmental impacts, including carbon footprint and environmental footprint;
- (p) expected generation of waste.

2. Ecodesign requirements shall, where relevant, ensure based on the product parameters referred to in Annex I that products do not become prematurely obsolete, for reasons that include design choices by manufacturers, the use of components which are significantly less robust than other components, the impeded disassembly of key components, unavailable repair information or spare parts, software that no longer works once an operating system is updated or software updates that are not provided.

* Ecodesign for Sustainable Products Regulation (ESPR) (Article 5: Ecodesign requirements)

NEW 130 °C P CONDUCTOR INSULATION PAPER

- Released by a major transformer OEM
- Mechanical, electrical, and chemical values match TUK conductor wrap paper specs
- Thermal class in mineral oil: 130 °C
- Thermal class in ester liquid: 140 °C
- Higher temperature limits for overload conditions
- End users can update their specifications for transformers used in the grid (e.g., N-1 and rated power)
- OEMs can redesign higher overload capable transformers
- Sustainable material solution





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THANK YOU