WHITE PAPER

INSULATION PERFORMANCE

ArmaPET Eco50 is the world's first polymeric insulation based on 100% recycled PET. Our new product solution designed for greater energy efficiency and reduced environmental impact of a building's lifecycle. The purpose of this white paper is to evaluate its long-term insulation performance and how this compares with other insulation materials.

www.armacell-core-foams.com

armacell®
ArmaPET®

ArmaPET® Eco50

ArmaPET Eco50 is the new solution for the structural insulation of building envelopes, roofs and floors, as well as for load-bearing applications such as under-slab insulation, in both the construction of new buildings and the renovation of older ones. ArmaPET Eco50 is the first polymeric insulation based on 100% recycled PET, combining an outstanding environmental profile with the stringent requirements of building construction. As part of the ArmaPET Eco range, this low-density product solution is optimised for energy-efficient structural applications.

// Reliable lifetime insulation performance

// 100% recycled material supports industry environmental directives

// Fully recyclable foam boards and cut-offs

// Prevents degradation caused by moisture, rodents and insects

// Robust material allows fast and easy handling

// Thickness up to 200 mm and flexible dimensions facilitate installation

// Superior compatibility with organic and mineral adhesives

Chapter 1 of this white paper will provide detailed insight into the basics of thermal insulation and definitions commonly used in this context. In chapter 2 we will further explore the thermal insulation performance of ArmaPET Eco50 and in chapter 3 we will provide insights into comparative studies that also consider other insulation materials under wet conditions.

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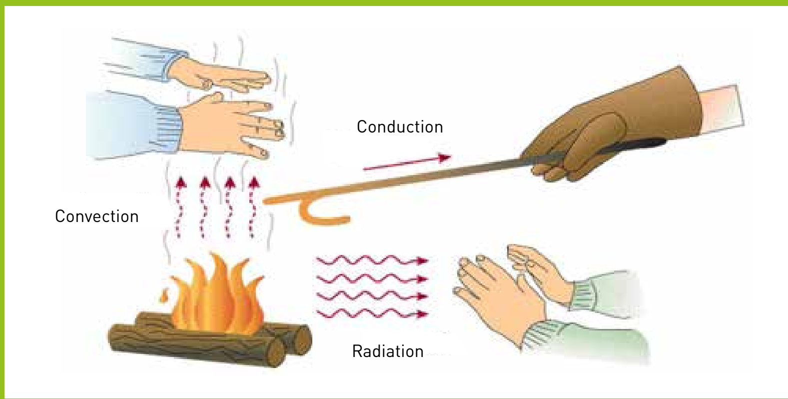
INSULATION MATERIALS – WHY ARE THEY NEEDED?

Heat is a form of energy associated with the random motion of molecules, atoms or smaller structural units of matter. According to thermodynamic laws, heat always flows from higher to lower temperatures. Depending on the application, insulation is required to prevent heat loss or heat ingress. Currently, due to eco-friendly mindsets and growing awareness of the earth's limited resources, thermal insulation is attracting increasing interest since it improves energy efficiency and comfort levels in buildings and systems.

A material's insulation properties describe the ability of heat to flow through the material. ArmaPET exhibits outstanding insulation properties even for high densities thanks to its closed cell structure and the high gas ratio within the material. In contrast to fibrous insulating materials, ArmaPET prevents water or liquid ingress by means of its closed cell structure, which ensures stable thermal properties over time.

HEAT FLOW
Heat flow occurs according to three phenomena: conduction, convection and radiation. Their principles are shown in the illustration beside:

Heat transfer by conduction is the most significant phenomenon regarding thermal insulation in the building and construction sector.



HEAT CONDUCTION
Heat conduction, also called diffusion, occurs within a body or between two bodies in contact. It is the direct microscopic exchange of kinetic energy of particles through the boundary between two systems, when an object is at a different temperature from another body or its surroundings.

HEAT CONVECTION
Heat convection depends on motion of mass from one region of space to another. Heat convection occurs when bulk flow of a fluid (gas or liquid) carries heat along with the flow of matter in the fluid.

THERMAL RADIATION
Radiation is heat transfer by electromagnetic radiation, such as sunshine, with no need for matter to be present in the space between bodies.

https://www.thermal-engineering.org/what-is-conduction-convection-radiation-definition/

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When speaking about insulation properties, a lot of different terms are used. In the following, we aim to explain the most common properties and how they are calculated.

DEFINITIONS

THERMAL CONDUCTIVITY / K-VALUE LAMBDA

Thermal Conductivity (TC) is also often expressed as lambda, denoted by the Greek symbol λ. It describes how easily heat passes through a specific type of material, independent of its thickness. The value is determined by specific measurement methods depending on the type of material and expressed in Watts per metre Kelvin **(W/m·K)**. The lower the thermal conductivity, the better the thermal insulation performance of a material.

THERMAL RESISTANCE / R-VALUE

The R-value is the common measure used to describe the resistance to heat flow of a specific material or assembly of components at a given thickness. In this case, the higher the value, the more thermal resistance the subject has and therefore the better its thermal insulating properties. The R-value is calculated as $\mathbf{R = {}^{t}/\lambda}$ (with t = thickness) and measured in metres squared Kelvin per Watt (m^2K/W).

In order to calculate the thermal resistance of a wall consisting of different layers, the different R-values of the layers are summed up as follows:

$$R_{wall} = \sum \frac{e_t}{\lambda_t}$$

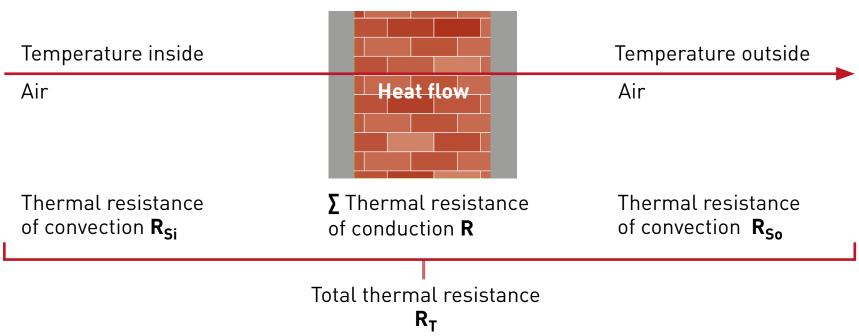
Where:

R is the total thermal resistance of the wall ($m^2.K.W^{-1}$)

t is the thickness of each component (m)

λ is the thermal conductivity of each component ($W.m^{-1}.K^{-1}$)

$$R_T = R_{Si} + R_{wall} + R_{So}$$



The R-value is a common way to compare performance of insulation layers. However, it only considers the conductive transfer of heat inside the part or wall assembly.

To determine the total thermal resistance of a wall system, the thermal resistance between the wall and the internal and external air layers (convection) needs to be added to the calculation. The thermal resistance describes the transfer of heat by convection from the air into the wall. This is referred to as R_{si} (inside) and R_{so} (outside). Typical values are dependent on the construction and tabulated data can be found in EN ISO 6946.

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$$U = \frac{1}{R_T} = \frac{1}{R_{Si} + \sum R + R_{So}}$$

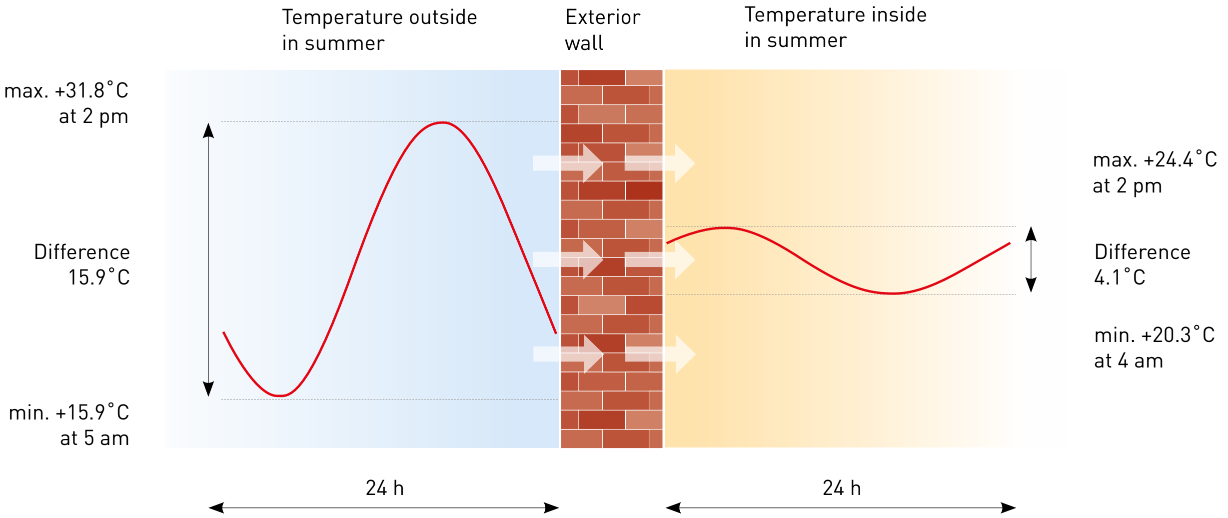
The lower the U-value of a structure, the better the heat insulation. There are several U-value calculation tools available, which can be used for specific set-up evaluations.

THERMAL TRANSMITTANCE / U-VALUE

The U-value represents the overall rate of heat transfer through an assembly such as a wall or a window including the frame. It considers conduction inside the material, convective heat transfer from the air into the building and radiation under standard conditions for a particular section of the construction. It is measured in Watts per metre squared Kelvin (W/m2K). The U-value then takes the R_T value into consideration and is calculated as **U = 1/R_T**

PHASE SHIFT

Phase shift describes the time interval that is needed for heat to pass from the external surface to the inside. This is an indication of the wall's capacity to store heat, thus ensuring that a house retains the heat from a warm day to prevent the house from cooling down during night or vice versa. This is especially important for preventing overheating of attics in summer or rapid cooling down of the house during the colder summer nights ("summer comfort"). The higher the phase shift value is, the better. It is calculated in time (minutes/hours). Another measure commonly used together with phase shift is amplitude attenuation. Amplitude attenuation describes how much a maximum or minimum temperature is dampened by the insulation of the building.



SUMMARY
λ = the lower the better
U = the lower the better
R = the higher the better
Phase shift = the higher the better

AMPLITUTE REDUCTION FACTOR
Temperature difference
outside: 15.9°C
inside: 4.1°C
= 3.87 = 1/TVA

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MEASURED THERMAL CONDUCTVITY AS PER EN 12667 AND RELATED R-VALUES

Since ArmaPET Eco50 is the first PET based insulation foam, there is no decidated product standard available for PET based insulation materials. Armacell has worked with external partners on a European Assessment Document (EAD), which allowed us to issue a European Technical Assessment (ETA) for the first ever CE-certified PET foam.

When ArmaPET Eco50 boards are tested a few days or weeks after production without special sample preparation, the measured lambda is as follows:

λ=W/m·K	50-200 mm
λ at 10 °C	< 0.030
λ at 23 °C	< 0.029
λ at 40 °C	< 0.028

R-VALUES

Which results in the following R-values:

$R=(m^2 \cdot K)/W$	50 mm	100 mm	150 mm	200 mm
R at 10 °C	1.67	3.33	5.0	6.67
R at 23 °C	1.72	3.45	5.17	6.9
R at 40 °C	1.78	3.57	5.36	7.14

DECLARED THERMAL CONDUCTIVITY AND THERMAL RESISTANCE

In building and construction applications with CE requirements in Europe, insulation products have to be compliant with their relevant harmonised product standards. Each common insulation material has its own harmonised standard where the performance evaluation as per international test norms is defined. These standards also define the sample preparation and measurement methods, which differ depending on the material type in order to reflect its typical behaviour.

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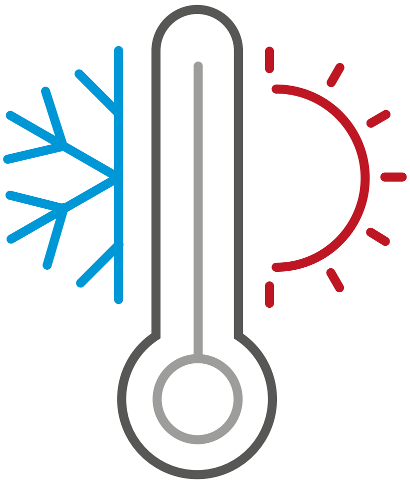
This is the baseline to determine the declared lambda (λ_D), which normally follows the $\lambda_{90/90}$ requirements, meaning that there is a 90% statistical certainty that 90% of tested samples will have a thermal conductivity equal to or lower than the declared value.

For PET foams as insulation products, no such norm yet exists. In order to obtain CE approval for the relevant applications, we have worked together with a notified body to create a European Assessment Document (EAD), which has been used as a basis to obtain a European Technical Assessment (ETA) for ArmaPET Eco50. The EAD and related ETA follow the harmonised product norm for XPS products, EN 13164, as this seems the most comparable product to PET foams.

In EN 13164, it is required to measure the lambda after ageing. This applies to all products that "are produced with the aid of blowing agents that have a lower thermal conductivity than air and which stay in the foam for an appreciable time"(EN 13164 Annex C 1 Scope). Ageing is obtained by the sample preparation in Annex C.2.2.



In accordance with EN 12667, which requires samples to be prepared as defined in the appropriate product standard, we have followed the official declared lambda for CE that is provided in EN 13164 as defined in the EAD for PET foams.

This means that, regardless of the thickness of the test specimen, it has to be cut down into slices of 10 (±1) mm. **These inidvidual slices have to be stored** at 23 (± 2)°C and 50 (± 5)% relative humidity for the following time periods:

// 90 (+ 2/– 2) days for XPS foam thicknesses of 20 to 70 mm,

// 50 (+ 2/– 1) days for foam thicknesses of > 70 mm to 120 mm

// and 30 (+ 2/– 0) days for foam thicknesses > 120 mm.

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For the testing, the slices are assembled to the test thickness again for measurement as per EN 12667.

As the EAD for PET foams follows the EN 13164 thermal conductivity requirements in all sections, it also means that the same correction factor (for [XPS] products without skin) of 0.0007 W/(m · K) applies.

When ArmaPET Eco50 is measured as per this ageing procedure and the calculation for the $\lambda_{90/90}$ statistical evaluation is applied, a λ_D of 0.035 W/m · K is achieved.

λ_D=W/m·K	50-200 mm
λ_D at 10 °C	0.035

R_D=(m²·K)/W	50 mm	100 mm	150 mm	200 mm
R_D at 10 °C	1.40 [3]	2.85 [3]	4.25 [3]	5.70 [3]

[3] Rounded downwards to the nearest of 0.05 (m² · K)/W.

However, the sample preparation that has been specifically designed for XPS does not fully reflect the actual behaviour of PET foams. The 10 mm slices do not represent the actual outgassing behaviour of ArmaPET in real use. Also, the dimensions of the samples are relatively small. As outgassing is more significant at the sides of a piece of material, the actual %-relation of the sides of the specimen is larger than for board dimensions in real use. For PET, no adjusted standard has been defined yet, but this is planned for the future to match its actual performance in use.

GERMAN “BEMESSUNGSWERT”

The German Energieeinsparverordnung (EnEV) requires an additional value called “Bemessungswert”, which includes additional safety upcharges. The DIBt (Deutsches Institut für Bautechnik) set the λ_B as 0.036 W/m · K for ArmaPET Eco50.

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PHASE SHIFT COMPARISON

The phase shift is important for evaluating how long a building can store energy in the walls and at what pace the energy travels through the walls. A slow pace and good ability to store energy prevents the inside of the house from getting warm too quickly when it is hot outside and ensures that, when the temperature drops, the walls store the energy for as long as possible to keep the temperature warm inside.

The phase shift of building materials increases with the material thickness. For the phase shift, the full wall assembly should also be taken into consideration. The target value for phase shift is described as > 12 hours[1]. Below is a table of the different materials and related phase shift in minutes per cm of material[1]:

MATERIAL	APPROX. PHASE SHIFT IN MIN. / CM OF MATERIAL
OSB (Oriented Standard Board)	43
Wood	40
Aerated concrete	24
ArmaPET Eco50	22
Solid brick	20
XPS	18
Concrete	17
Mineral wool	15
EPS	13

When comparing a 200 mm insulation board of XPS against a 200 mm insulation board of ArmaPET on a concrete wall of 200 mm, this would result in the following phase shift of the wall: Phase shift of wall x thickness + phase shift of insulation x thickness

Wall with ArmaPET Eco50 =
20x17 + 20x22 = 340 + 440 = 780 min = 13 hours

Wall with XPS* insulation =
20x17 + 20x18 = 340 + 360 = 700 min = 11.6 hours → In this case the insulation thickness should be further increased to meet the 12 hours for thermal shift.

Amplitute reduction factors:
XPS 1/TAV = 2.3 ArmaPET Eco50: 1/TAV = 3

*Density 35 kg/m³, 0.03 W/m·K

[1]Values as per https://sites.google.com/site/lowenergyhome/thermal-envelope/phase-shift

3 // INSULATION MATERIALS UNDER WET CONDITIONS

Working together with the FIW Institute (Forschungsinstitut für Wärmeschutz e.V München), we have evaluated the long-term thermal performance of PET, PU and XPS boards. The purpose of the test was to compare the thermal performance of PET with that of PU and XPS under the condition of high water contents due to absorption and adsorption as a result of water vapour diffusion to replicate real-use case performance.

MATERIALS USED FOR TESTING

For PET, ArmaPET Eco50 was used. It has a nominal density of 50 kg/m³ and is based on 100% recycled polyethylene terephthalate (PET) foam in accordance with EAD 040179-00-1201.
For the PU reference, a **CE-certified polyurethane** (PUR) foam with a nominal density of **30 kg/m³** was used. The manufacturer is known to Armacell.For the XPS reference, a CE-certified extruded polystyrene (XPS) foam with a nominal density of 30 kg/m³ was used. The manufacturer is known to Armacell.
All samples had a thickness of 50 mm and were provided in a dimension of 500 x 500 (length x width).

TEST PROCEDURE

All samples were stored for 180 days under the test conditions described in EN 12088 (long-term water absorption by diffusion) between a water bath of 50°C and a cold plate of 1°C. The storage was interrupted regularly to determine the water uptake and the thermal performance of the wet specimens as per EN 12664. This evaluation was done in a dry state, after 30 days, 60 days, 120 days and 180 days of water absorption by diffusion.
Heat fluxes due to redistribution of the water content inside the specimen. EN 12664 determines additional physical values in addition to thermal conductivity with which the thermal performance of moist materials can be described more accurately. Both physical values are comparable with the thermal conductivity (λ) described in EN 12667, but respect the influence of moisture in wet specimens:

// Hygrothermal transmission of a material (λ) in W/(m · K), as per EN 12664 section A2.9, which "applies to moist materials during steady state conditions when moisture distribution within the material is in equilibrium and there is no moisture movement within the material (with the possible exception of moisture circulating locally or within a pore)".

// Transfer factor of a specimen T in W/(m · K) according to EN 12664 section A2.8, which "characterises a specimen in relation to moisture migration and/or the combined conduction, convention and radiation heat transfer".

The hygrothermal transmission (λ) was chosen to interpret the measurement data. Measurements were taken to minimise additional transient and misleading heat fluxes by FIW during storage and testing.

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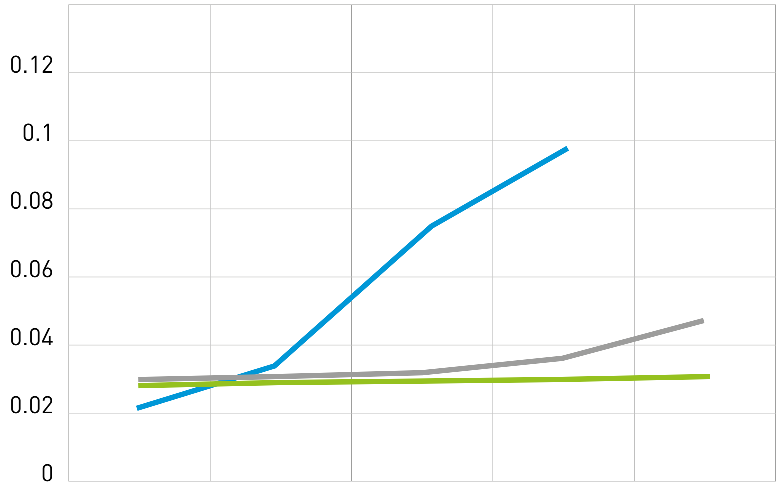
RESULTS & FINDINGS

Thermal conductivity (λ) [W/(m·k)] at 10°C in dry conditions and hygrothermal transmission (λ) [W/(m·k)] at 10°C until 180 days under water vapour absorption as per EN 12088



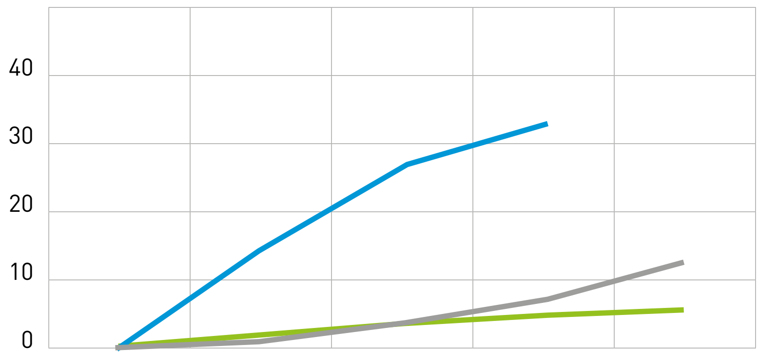
	Dry	30 days	60 days	120 days	180 days
ArmaPET Eco50	0.029	0.0294	0.0294	0.0297	0.0307
PU reference*1	0.0221	0.0354	0.0747	0.0977	
XPS reference	0.0312	0.0313	0.0327	0.0373	0.0443

Table 1: based on report L1-22-042a from FIW

*1 The PU reference was stopped after 81 days of water absorption because water content reached a level at which the product was starting to be incapable of keeping all adsorbed/ absorbed water inside its body.

Regarding the PU results at 60 and 180 days: Due to high water content, it can't be excluded that latent heat fluxes contributed to the thermal transmission. Therefore, the test results represent the "transfer factor of a specimen" T.

Water absorption*2 (vol - %) until 180 days under water vapour absorption as per EN 12088



	Dry	30 days	60 days	120 days	180 days
ArmaPET Eco50	0	2.6	3.6	5.1	6.6
PU reference*1	0	14.4	27.9	33.5	
XPS reference	0	2.0	4.0	8.1	12.6

Table 2: based on report L1-22-042a from FIW

*2 The levels of water content achieved were high above the hygroscopic level and also above the value typical for damage-free installation of insulation boards.

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Density [kg/m^2] dry and until 180 days
under water vapour absorption as per EN 12088

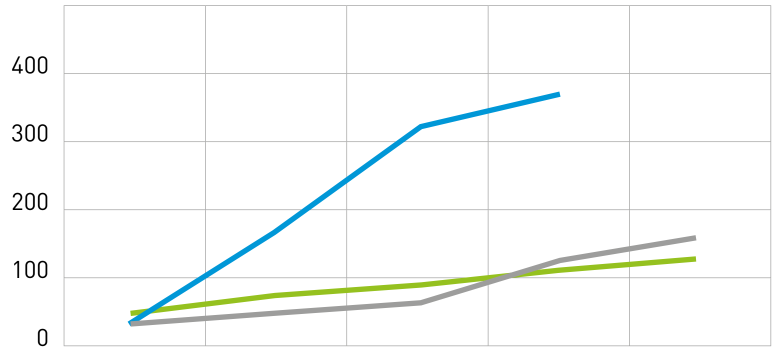

Table 3: based on report L1-22-042a from FIW

[*1]The PU reference was stopped after 81 days of water absorption because water content reached a level at which the product was starting to be incapable of keeping all adsorbed/absorbed water inside its body.

	Dry	30 days	60 days	120 days	180 days
ArmaPET Eco50	54	80	90	105	120
PU reference[*1]	32	176	311	367	
XPS reference	30	50	70	111	156

The charts show a clear trend of **high moisture absorption of the PU reference sample and a related decrease in thermal insulation performance over a short period of time**. It should be noted that this is likely not representative for all PUR materials and some will show less moisture intake. However, the trend of decreased thermal performance of PUR was also already proved in "New Wetting Curves for Common Roof Insulation" by Wayne Tobiasson, Alan Greatorex and Doris van Pelt in 1991, published in the International Symposium on Roofing Technology.
The same trend, while less significant, can also be found for XPS. While the starting density was lower than for PET (30 kg/m^2 compared to 54 kg/m^3), the final increase was 420% for XPS, resulting in a higher-density specimen after 180 days than the PET one (+122% in density). While the water absorption and related thermal conductivity are still comparable in the first 60 days ($\Delta\lambda$ 33 mW), we see a **steeper increase** after 120 days ($\Delta\lambda$76 mW) and 180 days ($\Delta\lambda$137 mW) in both **water absorption and the resulting reduced thermal insulation behaviour**. So, on overall thermal performance we see an increase of 0.013 mW from 0.0312 to 0.0443 W/(m · K).
For PET, we can recognise a water absorption of max. 6.6 vol-% after 180 days, which leads to only a small increase in thermal conductivity of 0.0017 mW, from 0.0290 to 0.0307 W/(m · K). This strongly supports the finding that PET has a **very stable insulation performance over time**.

SOURCES CHAPTER 1 // TERMINOLOGY

https://www.thermal-engineering.org/what-is-conduction-convection-radiation-definition/

https://www.thegreenage.co.uk/article/thermal-conductivity-r-values-and-u-values-simplified/

https://www.tec-science.com/thermodynamics/heat/thermal-transmittance-u-value/

https://www.firstinarchitecture.co.uk/a-quick-and-easy-guide-to-u-values/

https://sites.google.com/site/lowenergyhome/thermal-envelope/phase-shift

SOURCES CHAPTER 3 // INSULATION MATERIALS UNDER WET CONDITIONS

L1-22-042a from FIW München, dated 04.10.2021

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ABOUT ARMACELL

As the inventor of flexible foam for equipment insulation and a leading provider of engineered foams, Armacell develops innovative and safe thermal and mechanical solutions that create sustainable value for its customers. Armacell's products significantly contribute to global energy efficiency making a difference around the world every day. With more than 3,300 employees and 27 production plants in 19 countries, the company operates two main businesses, Advanced Insulation and Engineered Foams, and generated net sales of EUR 806 million and an adjusted EBITDA of EUR 121 million in 2022. Armacell focuses on insulation materials for technical equipment, high-performance foams for acoustic and lightweight applications, recycled PET products, next-generation aerogel technology and passive fire protection systems.

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