

Protection against energy losses

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Insulation
**increases the
efficiency of
mechanical
equipment**



WHY DOES TECHNICAL EQUIPMENT NEED TO BE INSULATED?

The contribution made by technical insulation materials to the operational reliability of mechanical equipment usually remains unseen. Yet they fulfil key functions: increasing the energy efficiency of the equipment, preventing condensation, ensuring corrosion protection, reducing noise emissions and keeping industrial equipment running. The importance of an insulation system usually only becomes apparent when it fails: ice on pipes and moisture in suspended ceilings due to condensation form-

ing on equipment, disruptions to industrial processes resulting in expensive maintenance work and downtime or rapidly rising energy consumption, to name just a few examples. According to a study conducted by ExxonMobil Chemical, 40 to 60 % of the costs for maintenance work on pipes are a result of corrosion under the insulation (CUI). The main cause is damp insulation which goes unnoticed.



The last thing you want: condensation dripping from the ceiling

In insulation technology, a distinction is made between the insulation of the building shell and the insulation of the technical equipment (i.e. the plumbing and HVAC equipment). The building shell is thermally insulated to minimize the extent to which heated buildings cool down or cooled buildings warm up and to provide a pleasant indoor climate. The building service equipment is thermally insulated to ensure that it works properly and to reduce the energy demand. So, in general, protection against heat or cold losses not only increases energy efficiency, but also safeguards the long-term operational reliability of the equipment.

While the main objective when insulating heating and hot-water pipes is to save energy, cold systems (such as the chilled-water pipes of air-conditioning systems or the suction lines of commercial freezers) also require protection against condensation and, in turn, corrosion. At the same time, insulation reduces performance losses in cold applications, too. Industrial equipment is insulated to stabilize production processes (e.g. to maintain the prescribed operating temperatures), to increase the effectiveness of the equipment and thus reduce costs. In addition, insulation protects the equipment against mechanical impact, raises long-term reliability and extends the service life by reducing operating cycles. It contributes to on-the-job safety by lowering the surface contact temperature on high-temperature equipment, for example. Furthermore, technical insulation provides acoustic protection by reducing the noise from installations and improves the indoor climate. Insulation materials must fulfil the relevant fire protection requirements, be easy to install even under difficult working conditions and – depending on the area of application – be highly resistant to chemicals and physiologically safe.

In the following, the central requirements made of technical insulation materials and key physical characteristics will be presented in detail.

REDUCING ENERGY LOSSES

Technical insulation materials minimize energy losses, i.e. heat or cold losses. Heat is transferred by conduction, convection and radiation. The key physical property for assessing insulation materials is the thermal conductivity.

Thermal conductivity

The thermal conductivity is the amount of heat that flows through 1 m² of a 1 m thick layer of a substance in one second when the temperature difference between the two surfaces is 1 K. The lower the thermal conductivity, the better the insulation properties of a material and the less energy is lost. The unit of thermal conductivity is watt per metre and per kelvin [W / (m · K)]; the symbol is the Greek letter lambda (λ). The thermal conductivity is a temperature-dependent material constant, i.e. it increases (slightly) as the temperature rises. For this reason, reliable insulation manufacturers only state the thermal

conductivity of their products in combination with the line temperature. This is usually written as an index, e.g. for AF/ArmaFlex: $\lambda_{0^\circ\text{C}} \leq 0.033 \text{ W}/(\text{m} \cdot \text{K})$.

Flexible elastomeric insulation materials (FEFs) have very good insulating properties. Depending on the type of elastomer, the thermal conductivity is between 0.033 und 0.040 W/(m · K) at a line temperature of 0° C. If a certain heat flow is required (i.e. must not be exceeded) space-savings can be achieved by varying the insulation thickness.

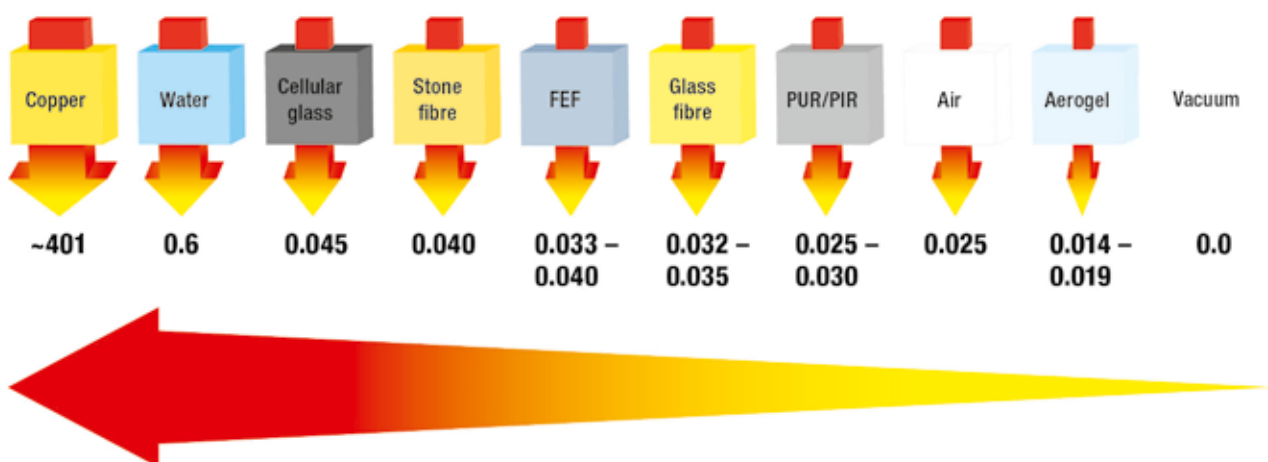
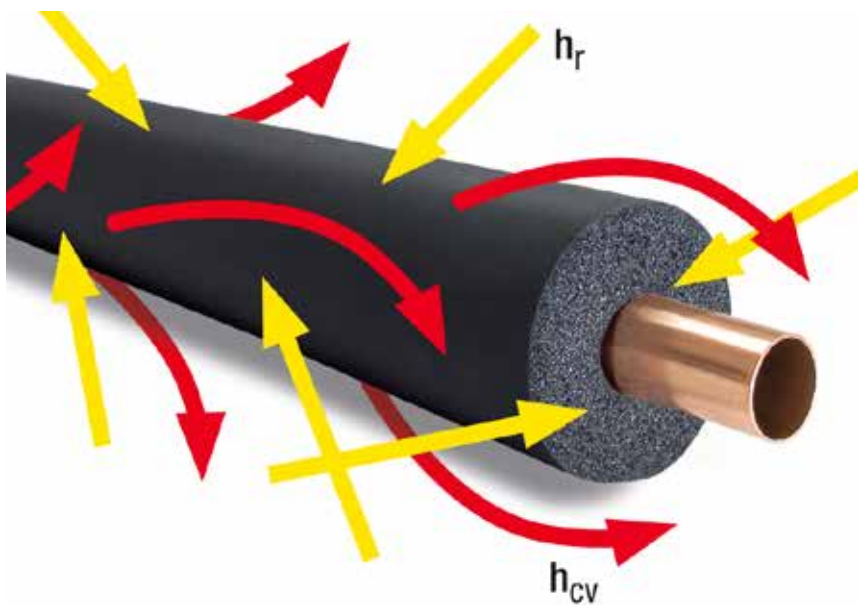


Figure 2: The thermal conductivity of various materials: the lower the λ -value, the higher the insulation capacity

Heat transfer

The heat transfer, i.e. the transport of heat between a fluid and a solid wall (e.g. the wall of a pipe or vessel), is mainly influenced by convection and radiation and it is described by the heat transfer coefficient. A distinction is made between the inner heat transfer (i.e. the transfer of heat between pipe or vessel medium and the pipe or vessel wall) and the outer heat transfer (i.e. the transfer of heat between the pipe or vessel wall or its insulation material and the ambient medium). The heat transfer coefficient usually consists of heat transfer through convection and heat transfer through radiation.

Unlike the thermal conductivity, the heat transfer coefficient is not a material constant, but depends on the type of flowing medium, the flow speed, the structure of the surface (rough or smooth, shiny or matt) and other parameters.



h_{cv} = heat transfer through convection
 h_r = heat transfer through radiation

Figure 3: Heat transfer coefficient

Convection

The convective part of the heat transfer coefficient makes a considerable contribution to preventing condensation on the surface of the insulation material. The faster the ambient air flows, the more heat is transported. Therefore, in practice it is essential to ensure that pipes and ducts do not lie too close to each other or to walls and other installations. Apart from the difficulties of installing insulation material properly if this is the case, there is also the danger of a build-up zone being created. In these areas, the circulation of air (convection) needed for a sufficiently high surface temperature is stopped, i.e. in such build-up zones the heat transfer coefficient is lower because the contribution of convection decreases. As a result, the risk of condensation increases significantly.

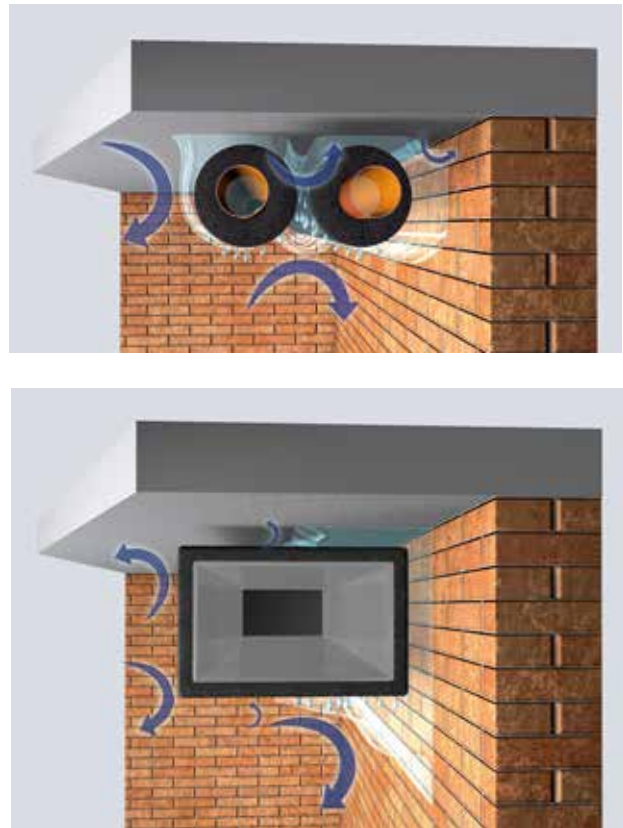


Figure 4: Convection

„The importance of an insulation system often only becomes apparent when it fails: dripping or icy pipes, damp suspended ceilings, corrosion under the insulation, rapidly rising energy consumption and even disruption to industrial processes, which can result in enormous costs due to maintenance work and downtime.“

Emissivity (ϵ) of various surfaces	
Material and surface condition	$\epsilon = a$
Aluminium foil, shiny	0.05
Aluminium, oxidized	0.13
Steel, galvanized, shiny	0.26
Steel, galvanized, dusty	0.44
Stainless austenitic steel	0.15
Alu-zinc, smoothly polished	0.16
Arma-Chek Silver	0.83
Paint-coated sheet metal	0.90
Plastic covering	0.90
Flexible elastomeric foam	0.93
Arma-Chek R	0.93
Arma-Chek D	0.94

Figure 5: Emission and absorption coefficients of the surfaces of various materials

Thermal radiation

Thermal radiation is a type of heat transfer where the heat is transported by electromagnetic waves. The transport of energy through radiation is not restricted to one transfer medium. Unlike thermal conduction or convection (heat flow), thermal radiation can also spread in a vacuum. In the case of thermal radiation, the mechanism of heat transfer consists of two sub-processes:

- Emission: heat is transformed into radiated energy on the surface of a body with a higher temperature.
- Absorption: the radiation which strikes the surface of a body with a lower temperature is transformed into heat.

Dark-coloured bodies emit more radiated energy than light-coloured ones. On the other hand, dark-coloured bodies also absorb more thermal energy than light-coloured ones

The measure for the emissivity of a material is the emission coefficient ϵ . The measure for the absorptive power is the absorption coefficient a . The emissivity of a body of a certain colour is exactly as great as its absorptive power. A completely black body has the greatest absorptive or emissive power. Figure 5 shows the emission and absorption coefficients of some surfaces of insulation systems. As can be seen from the table, it is largely the nature of the surface of the insulation material or its jacket – aside from the influence of other shining bodies – which determines the contribution of radiation a_s to the heat transfer coefficient. An insulation material on the basis of synthetic rubber absorbs much more thermal energy than, for example, an aluminium foil. This has an extremely positive impact on the insulation thickness required for condensation control, i.e. the higher the absorptive power, the thinner the insulation thickness needed to prevent condensation.

PROTECTION AGAINST MOISTURE INGRESS

In cold applications insulation must be protected against moisture ingress. On the one hand, moisture occurs due to condensation on the surface of pipes with line temperature below the ambient temperature. On the other hand, water vapour can diffuse into the insulation material due to the difference in vapour pressure, soon leading to damp insulation.

Preventing condensation

The air that surrounds us consists of various gases and water vapour. The water vapour content of the air can vary greatly. For example, in plants in which a lot of water is used, such as breweries or slaughterhouses, the water vapour content in the air will be much higher than in a normal office building. Yet the ability of air to absorb humidity in the form of water vapour is limited. In general it can be said that warm air can absorb more water than cold air. In practice this means that when atmospheric air with a certain temperature and a certain water vapour

content cools down in the vicinity of a cold pipe, its ability to absorb water falls (see Figure 6).

The actual amount of water vapour present in the air is referred to as the absolute humidity and measured in gram per cubic metre of air (g/m^3). The maximum humidity, on the other hand, states the maximum amount of water vapour which can be held in one cubic metre of air. It is temperature dependent, i.e. the amount is smaller in colder air than in warmer air. For example, air at $30\text{ }^\circ\text{C}$ can absorb a maximum of 30.3 g of water, while air at $5\text{ }^\circ\text{C}$ can absorb at most 6.8 g . If saturated air cools down from $30\text{ }^\circ\text{C}$ to $5\text{ }^\circ\text{C}$, 23.5 g of water will be released. Usually the absolute humidity is set in relation to the maximum humidity to arrive at the relative humidity. This value is multiplied by 100, resulting in a percentage value for the relative humidity. The symbol used is the Greek letter ϕ (phi).

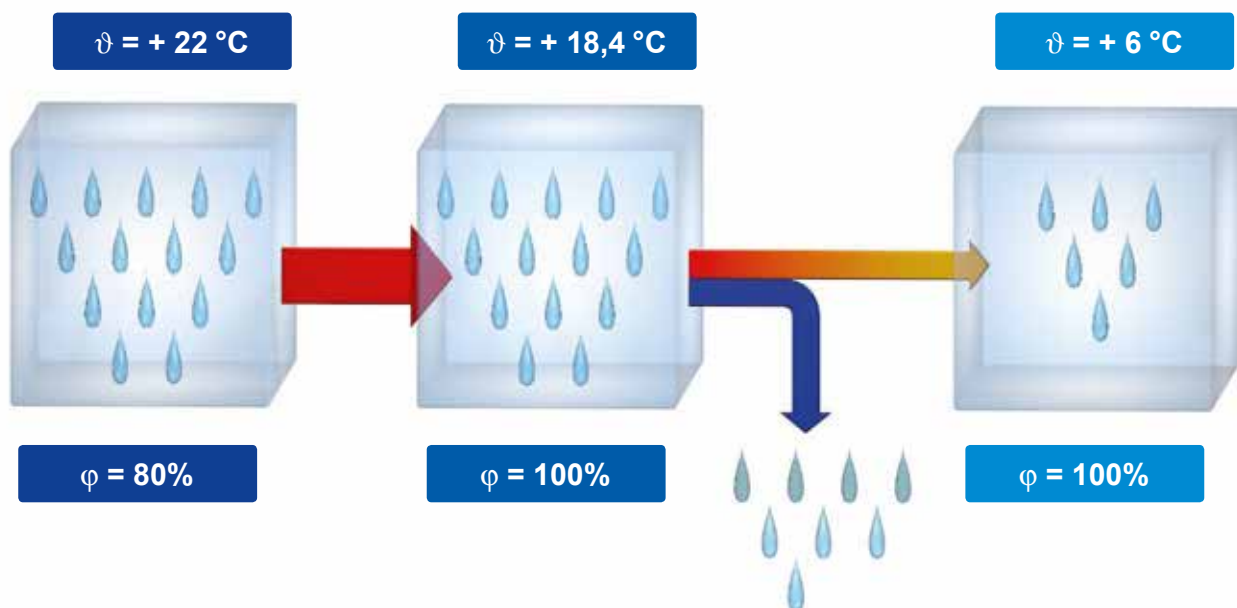


Figure 6: Air cannot absorb an infinite amount of water

Dew-point temperature and condensation

As the amount of water vapour does not decline as the air cools down, the degree to which the air is saturated increases as the temperature decreases. At a certain temperature the air is 100 % saturated. This temperature is known as the dew-point temperature. If the air now continues to cool down on the object, some of the water will no longer be absorbed in the form of (invisible) water vapour, but will become liquid water. Condensation, also known as perspiration water, is formed. To prevent condensation it is necessary to ensure that throughout the insulation the surface temperature on the insulation is always at least as high as, or better higher than, the dew-point temperature of the ambient air.

Water vapour diffusion

Water vapour diffusion (also known as water vapour transmission) is the natural movement of water vapour through construction and insulation materials. The driving force is the difference in water vapour pressure on the two sides of a component. Water vapour moves from the side with the higher pressure in the direction of the pressure gradient. The water vapour pressure depends on the temperature and relative humidity. The resistance to water vapour diffusion, also known as the μ -value (pronounced mu), indicates how many times greater the diffusion resistance of a layer of building material is compared to a static layer of air of the same thickness. μ is a temperature-dependent, dimensionless material property. The lower the μ -value of an insulation material, the greater the moisture content increase in the insulation due to diffusion processes, leading in turn to increased energy losses. Depending on the type of elastomer,

ArmaFlex has a resistance to water vapour diffusion of up to $\mu = 10\,000$. In individual cases, values of up to $\mu = 20\,000$ are achieved.

Water vapour diffusion equivalent air layer thickness

Another property for the resistance to water vapour diffusion is the water vapour diffusion equivalent air layer thickness (sd-value). Unlike the μ -value, this also takes the thickness of the construction material into account. It gives a clear description of the resistance to water vapour diffusion by indicating the thickness which a static layer of air would have to have in order for there to be the same diffusion flow under the same conditions as the material being examined. The sd-value describes how well or poorly a construction material performs as a vapour barrier. As Figure 4 shows, the static layer of air would have to be 190 m thick to build up the same resistance to water vapour transmission as 19 mm AF/ArmaFlex.

Water vapour diffusion equivalent air layer thickness of various materials	
Insulation	Water vapour diffusion equivalent air layer thickness
Air $\mu \sim 1, s = 100 \text{ mm}$	$s_d = 0.1 \text{ m}$
Mineral wool $\mu \sim 1, s = 100 \text{ mm}$	$s_d = 0.1 \text{ m}$
Polyurethane $\mu \sim 100, s = 100 \text{ mm}$	$s_d = 10 \text{ m}$
FEF $\mu \geq 5\,000, s = 100 \text{ mm}$ $s = 19 \text{ mm}$	$s_d = 500 \text{ m}, s_s = 95 \text{ m}$
AF/Armaflex $\mu \geq 10\,000, s = 100 \text{ mm}$ $s = 19 \text{ mm}$	$s_d = 1\,000 \text{ m}, s_s = 190 \text{ m}$

Figure 7: Water vapour diffusion equivalent air layer thickness of various

High energy losses due to moisture absorption

In cold applications it is essential that the insulation material is protected against moisture ingress. The insulating effect of a material is greatly diminished by moisture. Therefore, when selecting and determining the thickness for insulation in such applications, it is necessary to bear in mind that with insulation materials with a low μ -value energy losses can increase dramatically over the service life as a result of moisture penetration. Water has a much higher thermal conductivity than insulation materials. Therefore the absorption of moisture always leads to a rise in the thermal conductivity of the insulation material and a reduction in its insulation capacity. With every vol.-% of moisture content, the thermal conductivity increases and the insulation effect deteriorates. The consequences are not only higher energy losses, but also a drop in the surface temperature. If this falls below the dew-point temperature, condensation occurs. Only if the thermal conductivity of the insulation material does not increase significantly as a result of moisture penetration is it possible to guarantee that the surface temperature will remain above the dew point even after many years of operation.

Increases in the thermal conductivity of insulation materials depending on the moisture content were documented by Joachim Achtziger and J. Cammerer as early as the 1980s. They investigated the influence of moisture on the insulation capacity of various mineral wool insulation materials with raw densities ranging from 34 to 78 kg/m³.

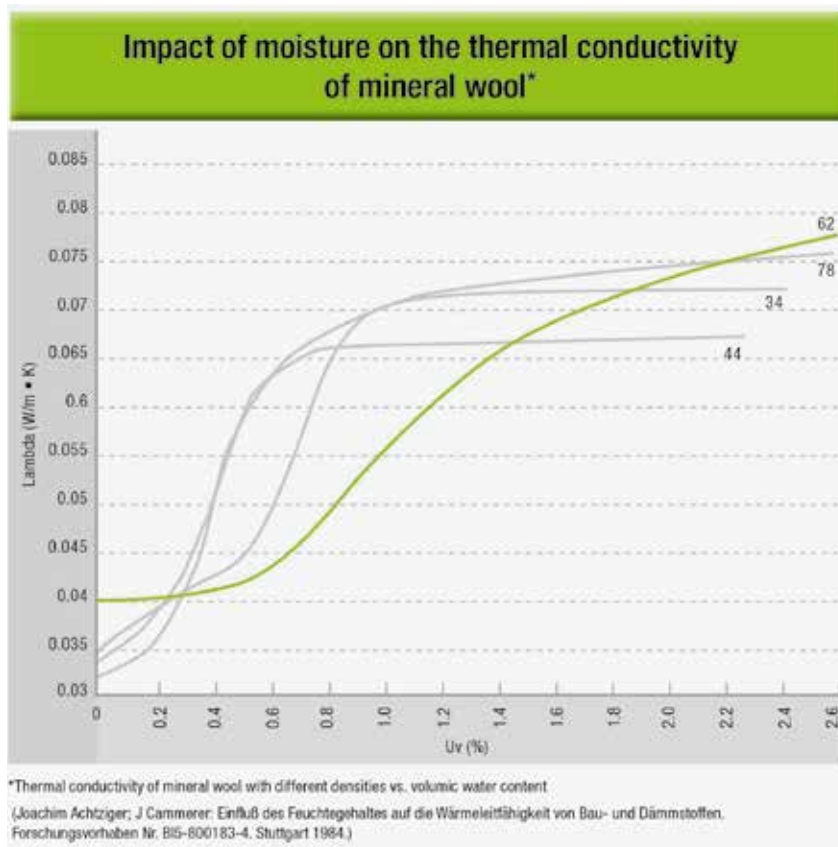


Figure 8: : Impact of moisture on the thermal conductivity of mineral wool



It should not look like this: insulation which works well at first, but on which condensation or – as here – even ice forms after the equipment has been in operation for a while

The way it should be: suitable, correctly dimensioned insulation materials prevent condensation



The insulation materials were installed on a copper pipe with a diameter of 35 mm, a line temperature of 60 °C and an ambient temperature of 22 °C. As shown in Figure 8, the thermal conductivity of mineral wool insulation with a density of 62 kg/m³ (green line) is 0.040 W/(m · K) at 0 % moisture content, yet rises to 0.075 W/(m · K) when the moisture content is 2.5 %. Even in the case of such slight moisture absorption, the insulation would have to be increased four-fold (from 30 mm to 120 mm) to achieve the same energy saving.

Flexible elastomeric insulation materials (FEFs) have a completely closed-cell structure and high resistance to water vapour diffusion. In the case of Armacell insulation materials the vapour barrier is not concentrated on a thin foil or the like, but built up throughout the insulation thickness – cell by cell. A separate vapour barrier is therefore not needed.

Higher energy savings thanks to optimal insulation

Preventing condensation on the surface is a minimum requirement which every insulation must fulfil on a long-term basis and even under critical conditions. The prerequisites for this are that the quality of both the material and the workmanship are high and that the correct insulation thickness is installed. Specifiers and installers who forfeit quality to keep costs down, who do not use suitable materials or specify and install insulation thicknesses which are too thin are taking an incalculable risk.

Minimum insulation thicknesses, which only prevent condensation, are not usually optimally designed for reducing energy losses. Installing greater insulation thicknesses results in significantly higher energy and CO₂ savings. Higher levels of insulation – i.e. insulation thicknesses that go beyond condensation control – require slightly higher investments, but these pay off over the service life and considerable financial savings are achieved after just a few years.



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