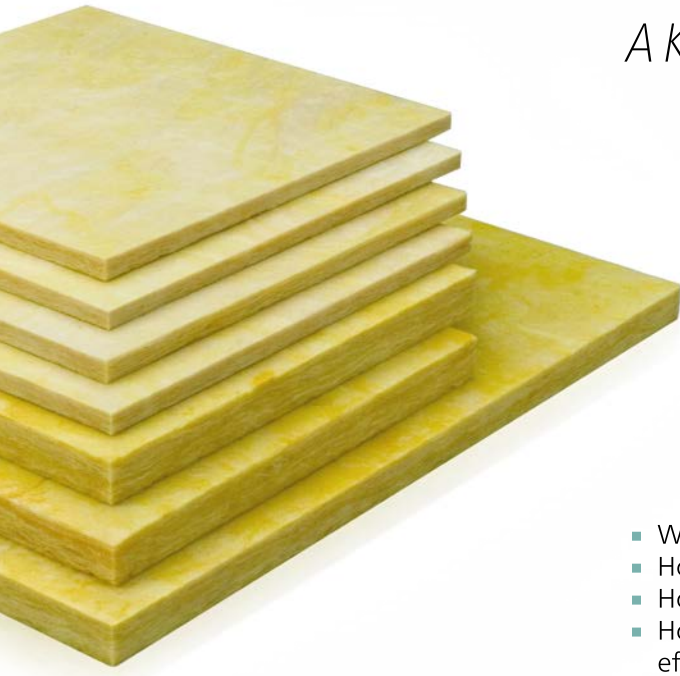
Proven Excellence.

HFM 446 *Lambda* Series – Heat Flow Meter for Testing Insulation Materials

Based on ASTM C518, ISO 8301, JIS A1412, DIN EN 12664, and DIN EN 12667
Method and Technique for the Characterization of Insulation Materials

Analyzing & Testing



A Key Parameter for Improved Energy Efficiency

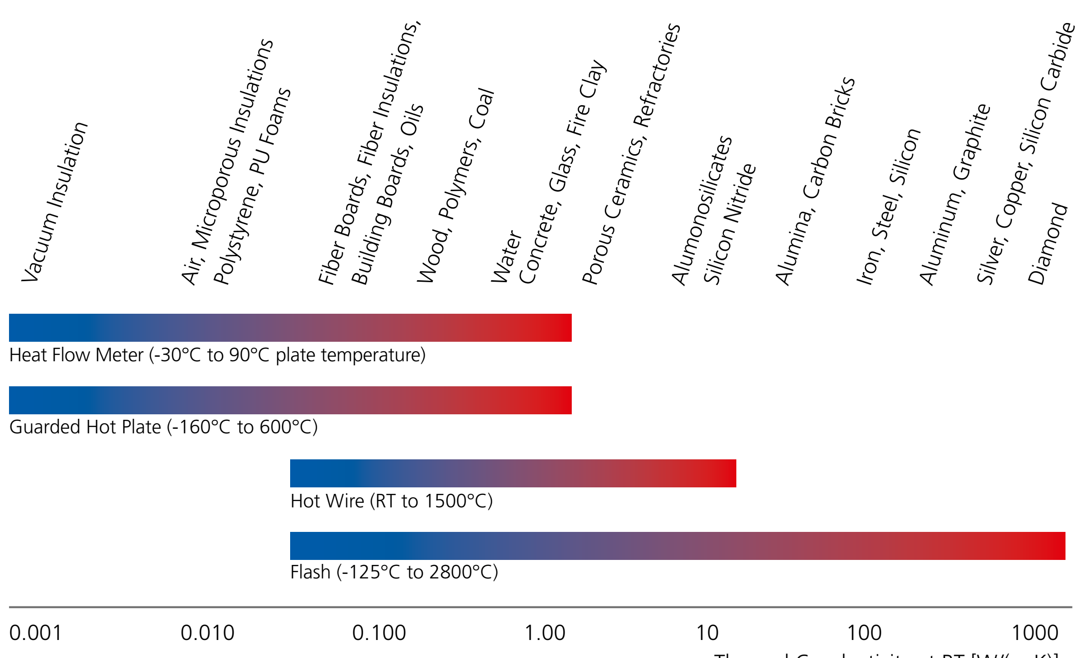
THERMAL CONDUCTIVITY

- What is the heating/cooling load of a building?
- How does this change with the weather and how can you improve it?
- How can you optimize the heat transfer from an electronic component?
- How do you design a heat exchanger system to achieve the required efficiency and what are the best materials to use?

To answer questions like these, material properties such as thermal diffusivity and thermal conductivity must be known. NETZSCH offers various thermal conductivity testing instruments covering nearly all possible applications and temperature ranges.

For the analysis of lower-conductivity materials such as fiber insulations or vacuum insulation panels, NETZSCH stands out with various types of heat flow meters (HFM) for diverse sample dimensions and temperature ranges.

The HFM 446 *Lambda* Series is based on various relevant standards, e.g., ASTM C518, ISO 8301, JIS A1412, DIN EN 12664* and DIN EN 12667.



* not for HFM 446 *Lambda Large*

The HFM is an exact, fast and easy-to-use instrument for measuring the low thermal conductivity λ of insulation materials.

PRINCIPLE OF OPERATION

In a heat flow meter (HFM), the test specimen is placed between two heated plates controlled to a user-defined mean sample temperature and temperature gradient to measure heat flowing through the specimen. The sample thickness L is measured by an internal thickness gauge. Alternatively, the user can enter and drive to the desired thickness, which is of particular interest for compressible samples. The heat flow $\dot{Q}$ through the sample is measured by two calibrated heat flux transducers covering a large area of both sides of the specimen.

After reaching thermal equilibrium, the test is done. The heat flux transducer output is calibrated using a reference standard. For the calculation of the thermal conductivity λ and the thermal resistance R, the average heat flux Q/A, the sample thickness L, and the temperature gradient ΔT are used, in accordance with Fourier's Law (see formulas on the right). The thermal transmittance, also known as U-value, is the reciprocal of the total thermal resistance. The lower the U-value, the better the insulating ability.

$$\lambda = \frac{\dot{Q}}{A}\frac{L}{\Delta T}$$

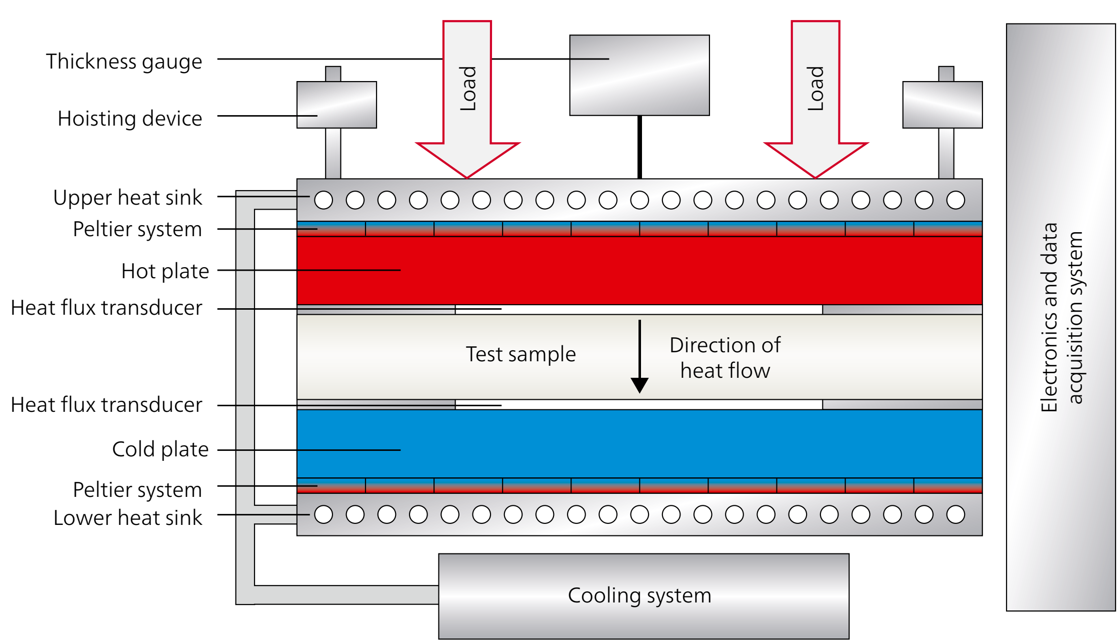
λ in SI unit [W/(m·K)] or British Thermal Units [Btu in/(h·ft²·°F)]

$$R = \frac{L}{\lambda}$$

R in SI unit [(m²·K/W)] or British Thermal Units [(h·ft²·°F)/Btu]

$$U = \frac{1}{R}$$

U in SI unit [W/(m²·K)]



The HFM is delivered calibrated.

HFM 446 *Lambda* Series

dedicated to small, medium and large-sized specimens ...

HFM 446 *Lambda Small*

HFM 446 *Lambda Medium*

SmartMode – Focused on Measurement, Evaluation and Reporting

The HFM software totally supports the operator with various easily understandable features including *AutoCalibration*, wizards, user methods and reports.

Heat Flux Transducer – High Sensitivity and Accuracy

The dual heat flux transducers monitor the heat flow to and from the specimen. For calibration of the sensors, a reference material is used with known thermal conductivity. Various calibrations can be combined to increase the accuracy of a measurement.

Determination of the Specific Heat Capacity

Besides measurement of the thermal conductivity, hardware and software allow for measurement and determination of the specific heat capacity c_p.

equipped with great features

HFM 446 *Lambda Large*

SMARTMODE

VARIOUS SAMPLE GEOMETRIES

HIGH PRECISION & ACCURACY

ADJUSTABLE TO NON-PARALLEL SPECIMEN FACES

EASY TO USE

$\lambda_{90/90}$

IN COMPLIANCE WITH STANDARDS

ECO-MODE

STAND-ALONE OPERATION

QA DOCUMENTATION

FULLY SELF CONTAINED

FAST MEASUREMENT

VARIABLE LOAD

THICKNESS DETERMINATION

c_p MEASUREMENT

EXTENDABLE TO LOWER THERMAL RESISTANCES

WIZARDS & METHODS

Saving Ressources in Eco-Mode

In standby, the HFM 446 *Lambda* can be switched to the energy-saving Eco-Mode or to Idle-Mode for a quick measurement start. The timing for when each mode is active can be adjusted via a scheduler.

The λ Solution

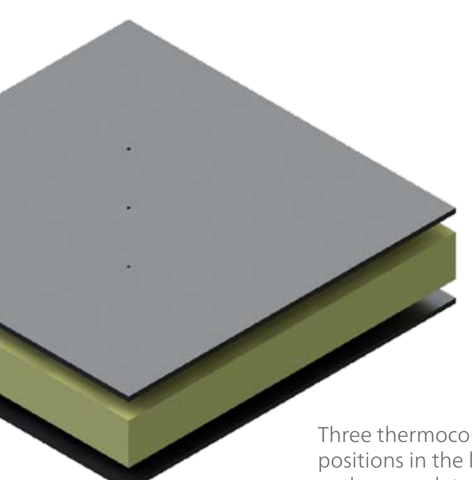
Fast sample change without affecting the plate temperatures

Peltier Temperature Control for Hot and Cold Plates

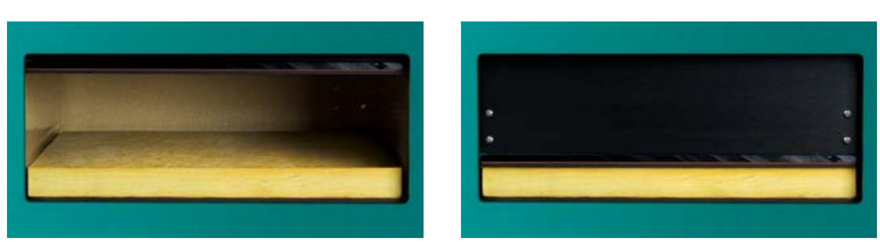
The plate temperatures are individually controlled by bidirectional heating/cooling Peltier systems connected to an external chiller. Thanks to optimized temperature control, the high-output Peltier elements accomplish thermal equilibrium and data sets within a short time – a productivity increase for your laboratory.

Motorized Plate Movement and Furnace Door

The plates of the HFM 446 *Lambda* can be separated just slightly at the end of a test. For the next test, change of specimens can thus be done within seconds. Disturbances in the plate temperatures are therefore minimized and the plates can quickly return to the set point. The subsequent test thus has a head start in its approach to equilibrium. The *Small* and *Medium* versions have a motorized front door.



Three thermocouple positions in the lower and upper plates



Various plate openings of the HFM 446 *Lambda* are possible when changing the specimen

Measuring the thermal conductivity of compressible materials at variable density

Variable Load – control of thickness and density of compressible samples

The operator can define a contact force of up to 850 N (HFM 446 *Lambda Small*) or 1930 N (HFM 446 *Lambda Medium* and *Large*). This enables control of the thickness, and thus density, of compressible materials.

It also ensures that the plates make intimate contact with the specimen across the entire surface in order to produce minimal and uniform contact resistance – two necessary requirements for obtaining reproducible thermal conductivity results.

Integrated Thickness Measurement

The HFM 446 *Lambda* Series comes with an integrated µm-resolution transducer, allowing the measurement of the specimen's actual thickness within a few seconds. On the upper plate, a two-axis inclinometer is integrated. The construction allows for many sample geometries specifically for inclined and nonparallel specimens without any stress on the motor shafts.

Measuring frame for loosely filled material

Precise control regulates thickness and therefore, also the density of compressible materials

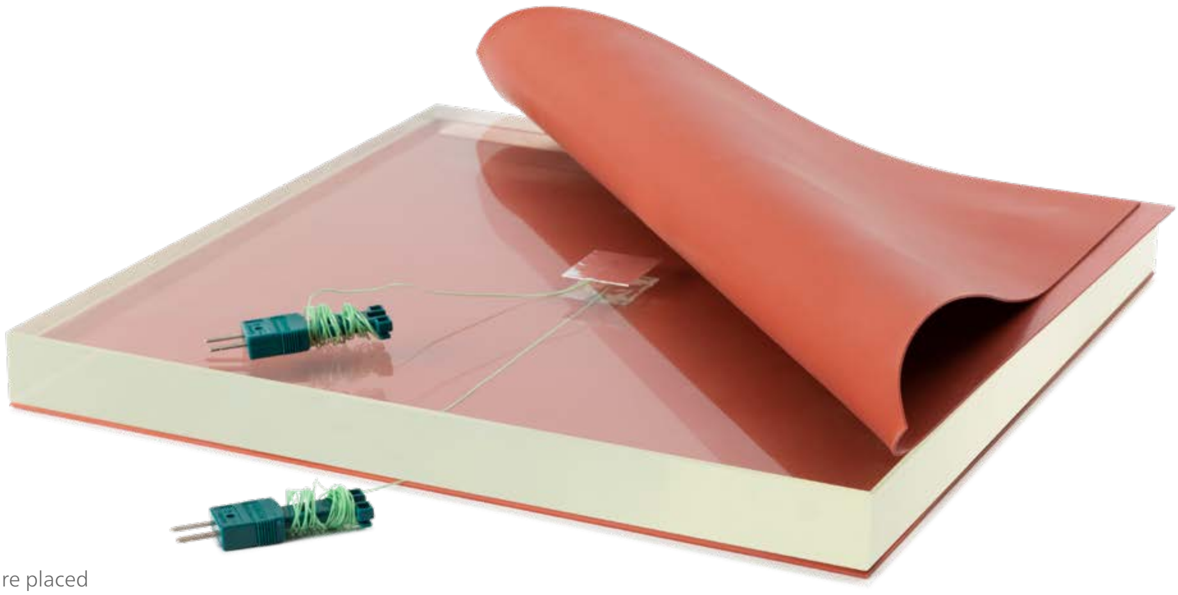
Materials beyond the routine capability of the HFM method can be tested by insertion of additional thermocouples and rubber interface pads – eliminating the impact of interface resistance for low thermal resistance and accordingly higher thermal conductivity materials.

Improved Measurement Precision for Rigid Specimens with Low Thermal Resistances

The HFM 446 *Lambda* series can be equipped with an optional instrumentation kit* that expanding its range to lower thermal resistances (down to 0.02 (m^2·K)/W) like concrete, wood products, brick, etc.

The optional kit includes thin, compressible rubber pads for use at both interfaces, and auxiliary thermocouples to be fixed on both surfaces of the specimen. This increases the temperature accuracy – especially for applications which require enhanced temperature sensing.

* For HFM 446 *Lambda Large*, on request



Thermocouples are placed in the specimen's center

The instrument is delivered calibrated and a reference specimen is optionally included for verification. Of course, the list of available reference materials can be extended by the operator.

ACCESSORIES *AND MORE*

Pre-calibrated with Certified Reference Materials

The HFM system is delivered calibrated with an NIST-certified or IRRM reference standard of known thermal conductivity. This establishes precise correlation between the signal output of the transducers and the actual heat flow. Thermal resistance and thermal conductivity are determined once the user-defined stability criteria are met. Of course, the customer can also use his own reference materials. For the above-mentioned reference specimens, an accuracy of ± 1% can be easily achieved.

Inserting the reference material; various reference materials can be used

HFM 446 Lambda Small and Medium are able to measure the specific heat capacity c_p

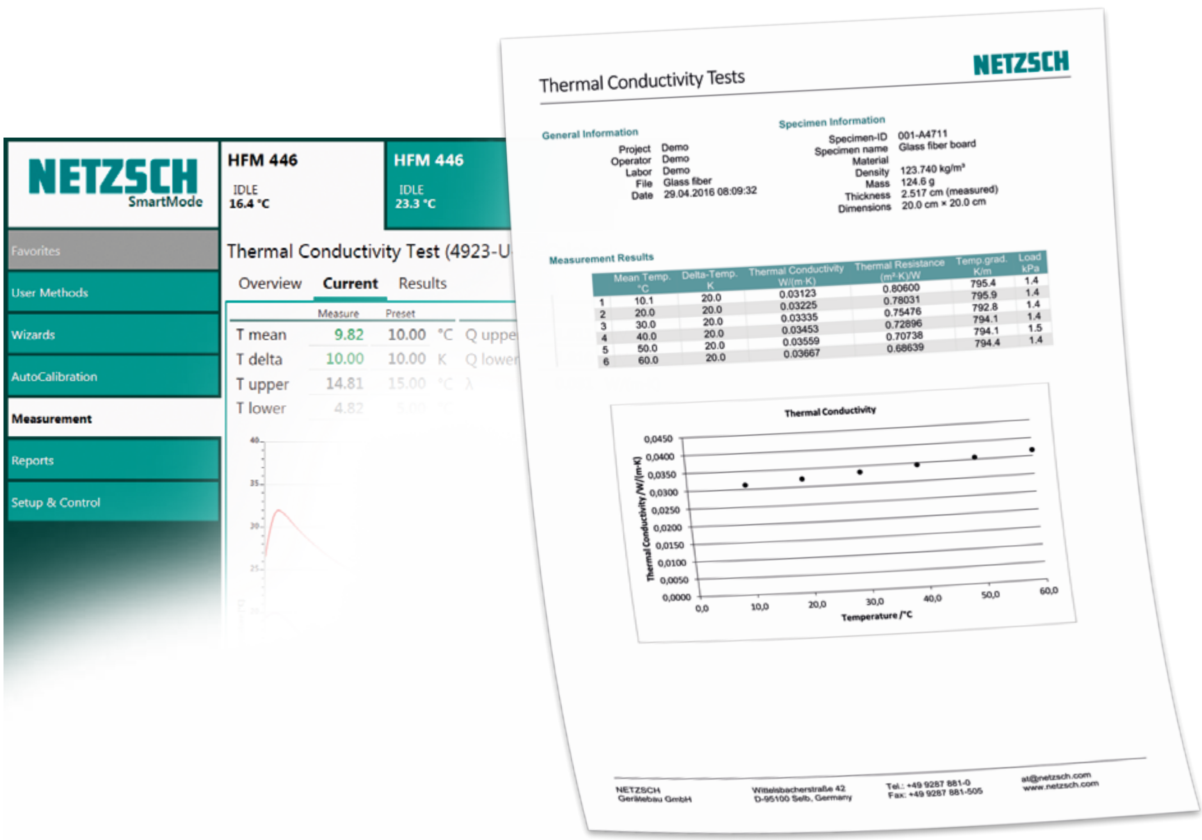
Best Test Condition with Reduced Risk of Condensation

The design of the testing chamber of the HFM 446 *Lambda* Series minimizes influences from the environment and reduces condensation effects inside the testing chamber and on the plate surfaces. Optionally, the testing chamber can be purged with dry gas.

C_p Measurement

Along with the thermal conductivity, the HFM 446 *Lambda Small* and *Medium* instruments allow for determination of the specific heat capacity c_p by using the calibration factors and accounting for contribution of the thermal mass of the plates.

Software Interface



Highest Usability

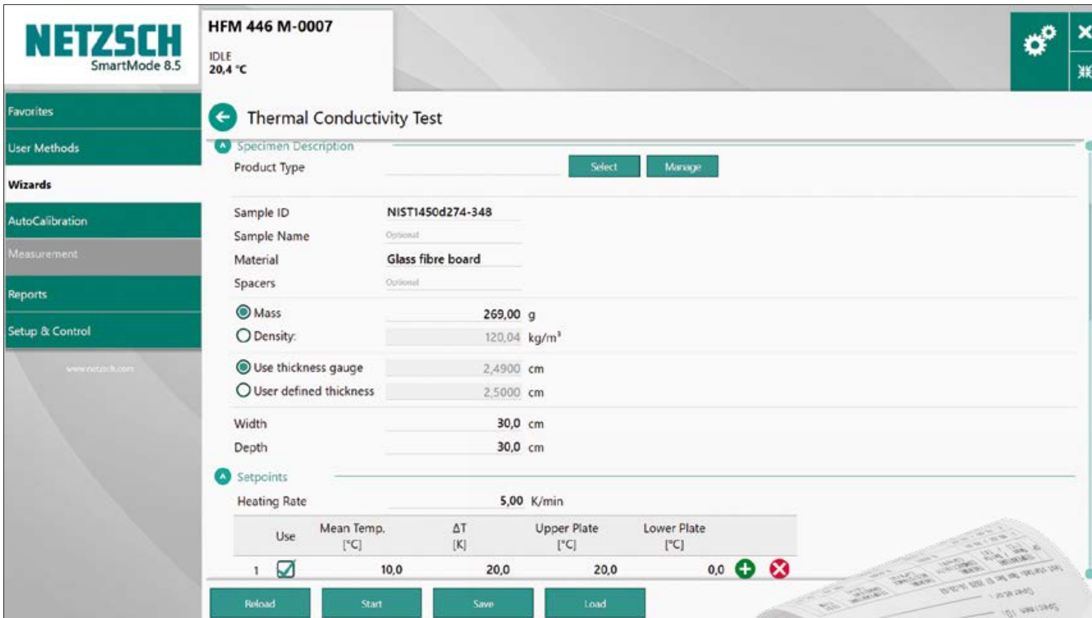
SmartMode is the user-friendly, smoothly running user interface of the HFM *Proteus*® software. It is characterized by a logical structure which quickly gives a clear overview of the current measurement status and provides various report and export possibilities. After completing the test, all relevant results can be directly printed out by the integrated printer or a report can be created by the software when a PC is connected.

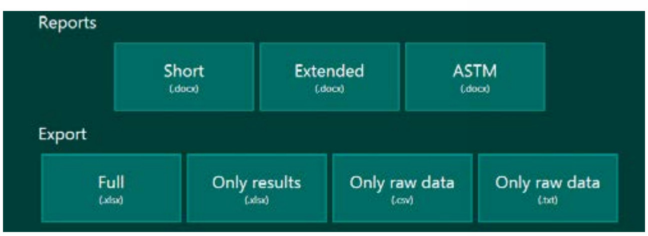
Calibration in Next to no Time

For calibration purposes, the thermal conductivity values of the most common certified reference materials, such as NIST SRM 1450d, are already stored in the software. However, *AutoCalibration* also offers the ability to create calibration curves for any user-defined material on the basis of up to 99 freely selectable temperatures.

Wizards and Methods Guide You to the Results

The "Wizards" button allows for manual parameter input, while the User Methods button retrieves parameter sets defined by the user beforehand. Such "User Methods" can also be transferred to "Favorites" for faster access if they are used frequently.





Printout of the results obtained by the integrated printer

Complete QA Documentation – Just a Click Away

The button "Reports" allows for reports to be generated quickly and easily by granting access to various templates; one of these templates meets all of the requirements stipulated by ASTM C518. Each report can be adapted to the customer's own corporate identity. In addition, data can easily be exported into either Word or Excel format with just a few mouse clicks. The "Full" export button exports data, graphs and results together into a single file. Measurement data is stored in binary format and is thus fully tamper-proof.

Statistics: $\lambda_{90/90}$

The $\lambda_{90/90}$ value is the basis for determination of the declared value of the thermal conductivity within the realm of CE declarations of building materials. It is calculated from a measurement series of at least 10 measurements and states which thermal conductivity values to a probability of 90%, can be achieved for 90% of the output production volume. The integrated report calculates the $\lambda_{90/90}$ value by a mouse mouse click. The calculation is based on your measurements; no additional documentation and calculation are required.

Setup & Control

Any measurement can be started by using the pre-defined instrument parameters (including number and position of thermocouples, stability criteria, etc.). However, experienced users who wish to apply their own parameter sets can define them under "Setup & Control".

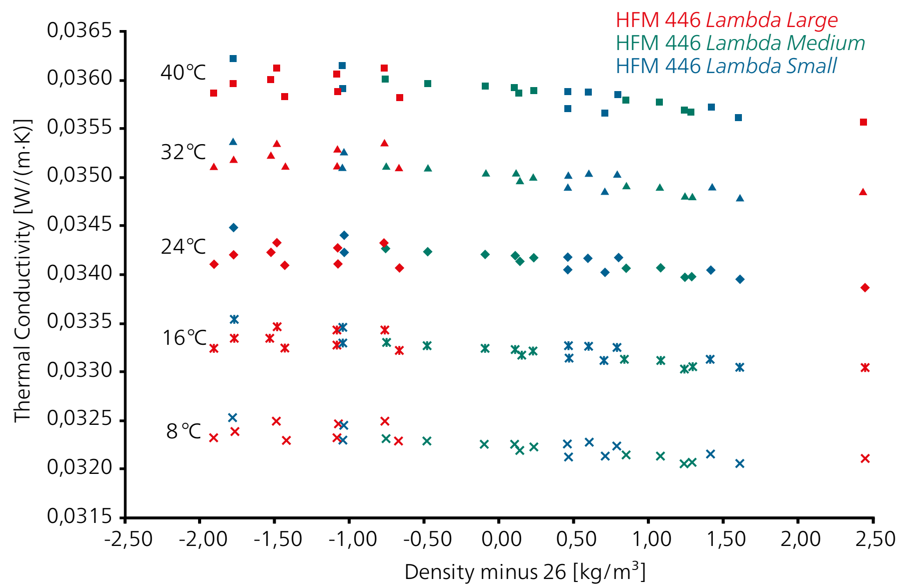
Performance & Applications

Performance Checked on EPS Material

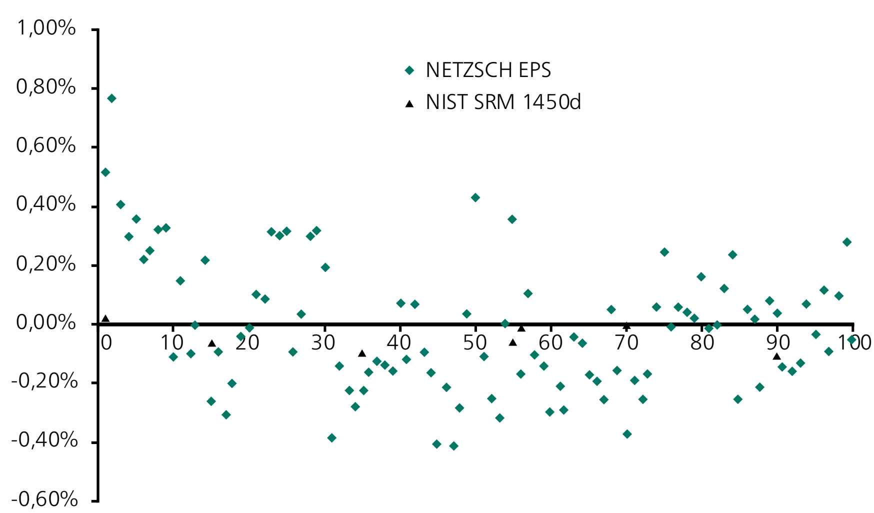
In addition to certified reference materials from NIST and NPL, NETZSCH offers its own factory standard for the calibration and validation of HFM devices in the temperature range 8 ... 40°C: NETZSCH EPS (expanded polystyrene).

The upper figure shows that the thermal conductivity of NETZSCH EPS measured for 10 different specimens with the dimensions of 600 mm x 600 mm x 25 mm (HFM 446 *Lambda Large*), 300 mm x 300 mm x 25 mm (HFM 446 *Lambda Medium*) and 300 mm x 300 mm x 25 mm (HFM 446 *Lambda Small*) is reproducible to within about ± 0.5%. The mean thermal conductivity (formula stored also in the software) depends on the temperature and also slightly on the specimen density (mean value 26 kg/m³).

The lower figure is also evidencing the thermal conductivity's excellent reproducibility of better than ± 0.5%. During a period of 2 to 3 weeks, 100 different NETZSCH EPS specimens were measured.



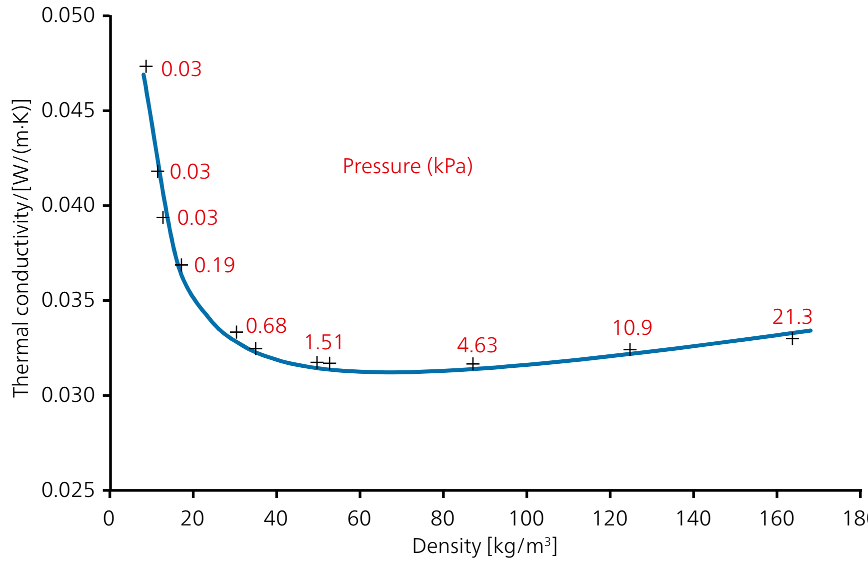
Temperature- and density-dependent thermal conductivity of 30 different NETZSCH EPS specimens.



Relative deviation of the thermal conductivity λ from nominal values of 100 different NETZSCH EPS specimens of the size 300 x 300 x 25, measured in an HFM *Lambda Mediuim* device at a mean sample temperature of 40°C and a gradient ΔT of 20 K (green symbols; black symbols NIST SRM 1450d Standard).

Investigation of the Correlation Between Density and Thermal Conductivity of Compressible Materials

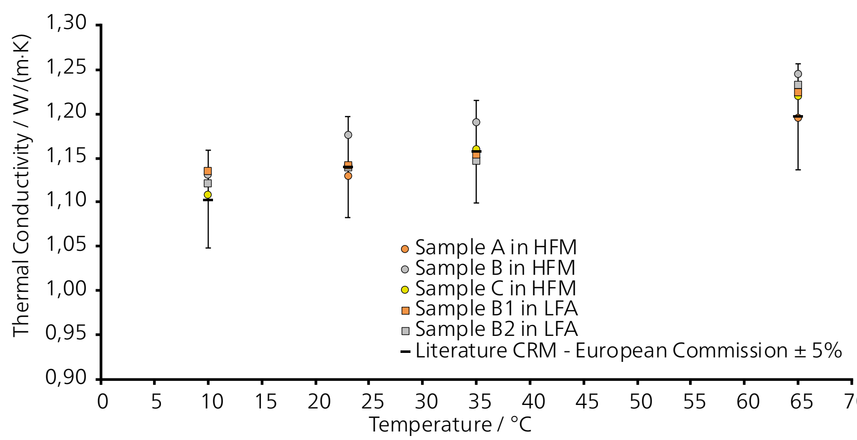
With the "Variable Load" feature, the density-conductivity correlation of compressible materials can be investigated. The case study presented here validates the expected multi-mode heat transfer within glass-fiber insulations. While the specimen is progressively compressed with an increasing load, represented here by the equivalent surface pressure, the combined conductivity first decreases due to a reduction in radiative heat transfer, and then increases as conductive heat transfer becomes more predominant.



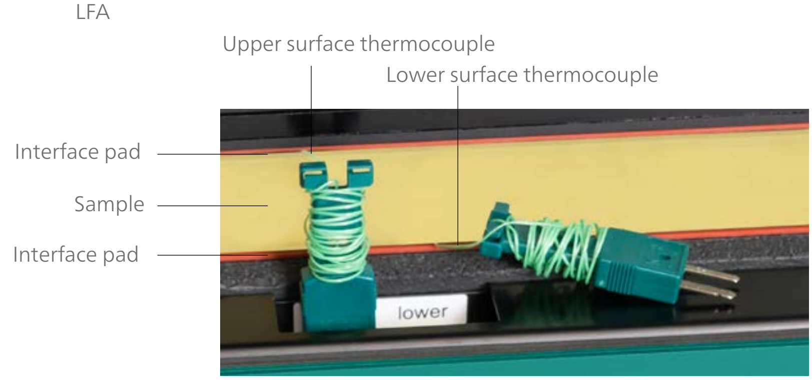
Thermal conductivity of a glass-fiber as a function of density

Low Thermal Resistance – Measurable in the HFM 446 *Lambda* Series

The use of the instrumentation kit (see page 8) is crucial for materials featuring low thermal resistance. A borosilicate glass plate with a thickness of 25 mm and a thermal conductivity of 1.14 W/m/K at 23°C [1] has a thermal resistance of approximately 0.02 (m^2K/W). With the use of the instrumentation kit, the thermal conductivity measurement results on three Borosilicate glass plates from one batch show very good accordance with the measurement results from the Laser Flash Analysis (LFA). Over the whole temperature range, the relative deviations for the HFM instrument amount to a maximum of 3.9% and for the LFA to a maximum of 2.8%. Therefore, both measurement methods are within the stated uncertainty of ± 5% for this material.



Thermal conductivity of borosilicate glass plates, measured by means of HFM and LFA



Use and comoponents of the instrumentation kit

Literature : [1] I. Williams, R. E. Shawyer: Certification report for a pyrex glass reference material for thermal conductivity between -75°C and 195°C; Commission of the European Communities; Luxembourg; 1991

C_p Measurement

For measurement of the specific heat capacity, c_p, with the HFM 446 *Lambda*, both plates are held at exactly the same temperature. When there is no more heat flux between the two plates, a temperature step is initialized. Heat-flux transducers measure the resulting heat flux into the sample and the plates, the signal is integrated and evaluated. By performing a so-called empty stack measurement (system without sample) prior to the sample measurement, the specific heat of the system is taken into consideration.

The HFM 446 *Lambda Small* and *Medium* versions can measure the specific heat capacity (Si unit J/(g·K)) of solid polymers such as polyamide or PVC, and of insulation materials such as glass wool.

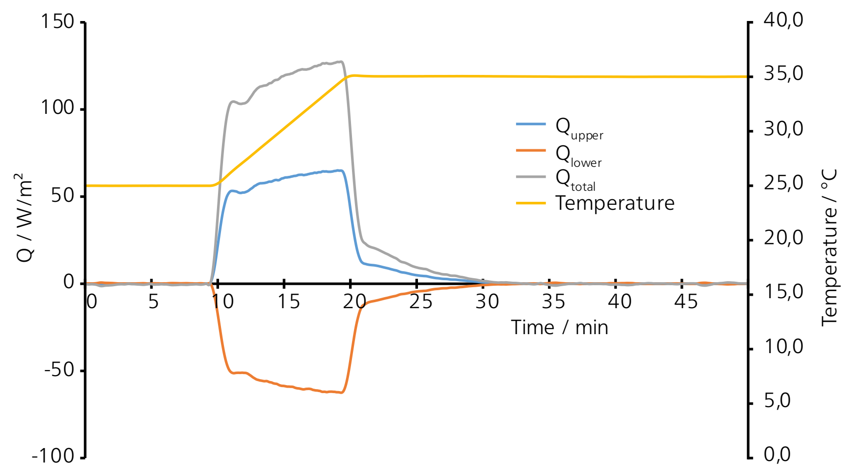
Specific Heat Capacity of a Glass Fiber Insulation

Not only the thermal conductvity but also the specific heat capacity of insulation materials is an important material property in the building sector. A high specific heat capacity of an insulation material can dampen temperature changes of the outer environment and contribute to a constant indoor climate.

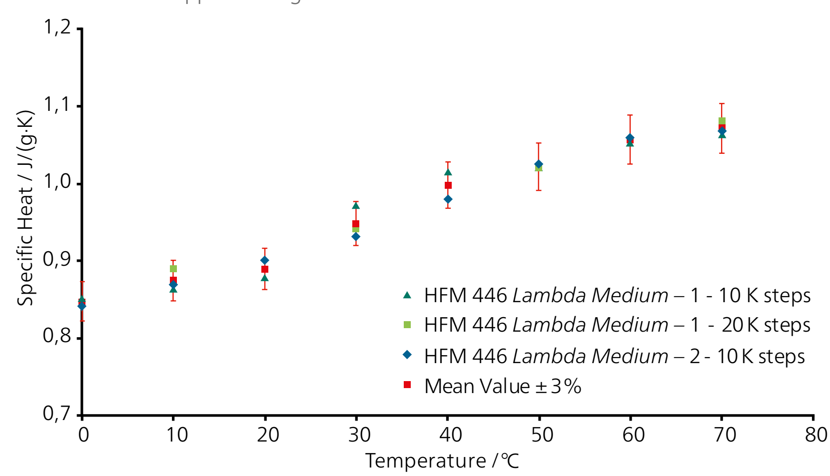
Glass wool was investigated with two different HFM 446 *Lambda Medium* devices within a temperature range of 0°C to 70°C and different temperature steps (10 K and 20 K).

The upper figure shows the measurement signals of the temperature and heat flux of one temperature step versus time of the glass fiber sample. The resulting combined heat flux Q_{total} of the upper and lower plates (Q_{upper} minus Q_{lower}) represents the heat consumption, necessary to heat up the sample (incl. the plates). Based on the integral and the empty stack measurement carried out previously, the specific heat capacity at a mean temperature of 30°C can be determined.

The lower figure shows that the specific heat capacity of the glass fiber insulation increases with higher temperatures. The results of all measurements vary within ± 3 % around the mean value and are within the expected range for glass wool of < 1 J/(g·K) at RT.



Heat flux and temperature of one temperature step between 25°C and 35°C during a c_p measurement with the HFM 446 *Lambda Medium* on a glass fiber insulation featuring sample dimensions of approx. 30 cm x 30 cm x 2.5 cm and a mass of approx. 300 g



Specific heat capacity of a glass fiber insulation between 0°C and 70°C

This clearly demonstrates that the HFM 446 *Lambda* is capable of determining the specific heat capacity of large-volume and inhomogeneous materials typical for applications in the building and insulation industries.

Technical Specifications

	HFM 446 *Lambda* Series
Standards	ASTM C518, ISO 8301, JIS A1412, DIN EN 12667, DIN EN 12664*
Type	Stand-alone, with integrated printer
Thermal conductivity range	▪ *Small*: 0.007 to 2 W/(m·K)** ▪ *Medium*: 0.002 to 2 W/(m·K)** ▪ *Large*: 0.001 to 0.5 W/(m·K)** *Small* and *Medium*: 2.0 W/(m·K) achievable with optional instrumentation kit, recommended for hard materials and those with higher thermal conductivity Performance data: ▪ Accuracy: ± 1% to 2% ▪ Repeatability: ± 0.25 % ▪ Reproducibility: ± 0.5% → All performance data is verified with NIST SRM 1450 D (thickness 25 mm)
Plate temperature range	-20°C to 90°C, optional for the HFM 446 *Lambda Medium*: -30° to 90°C
Air-tight system	Sample compartment with possibility to introduce purge gas
Metering area heat flux transducer	▪ *Small/Medium*: 102 mm x 102 mm ▪ *Large*: 254 mm x 254 mm
Chiller system	External; constant temperature setpoint over plate temperature range
Plate temperature control	Peltier system
Plate motion	Motorized
Plate thermocouples	Three thermocouples on each plate, type K (two extra thermocouples with instrumentation kit)
Thermocouple resolution	± 0.01°C
Number of setpoints	Up to 99
Specimen sizes (max.)	▪ *Small*: 203 mm x 203 mm x 51 mm ▪ *Medium*: 305 mm x 305 mm x 105 mm ▪ *Large*: 611 mm x 611 mm x 200 mm
Variable load/ contact force	▪ *Small*: 0 to 854 N (21 kPa on 203 x 203 mm^2) ▪ *Medium*: 0 to 1930 N (21 kPa on 305 x 305 mm^2) ▪ *Large*: 0 to 1900 N (5 kPa on 611 x 611 mm^2) Force-controlled adjustment of the contact force or the desired thickness, and thus density, of compressible materials
Thickness determination	▪ Automatic measurement of mean sample thickness ▪ Four-corner thickness determination via inclinometer ▪ Compliance to non-parallel specimen surfaces
Software features	▪ *SmartMode* (incl. *AutoCalibration*, report generation, data export, wizards, user methods, predefined user definable parameters, user-defined parameters, c_p determination, etc.) ▪ Storage and restoration of calibration and measurement files ▪ $\lambda_{90/90}$ Report ▪ Plot of plate/mean temperatures and thermal conductivity values ▪ Monitoring of heat flux transducer signal ▪ Creation/selection of configurations for stand-alone-operation (without PC)

* not HFM 446 *Lambda Large*
** Please note: In the very low thermal conductivity range, accuracy of Lambda (λ) values can be restricted.

The NETZSCH Group is an owner-managed, international technology company with headquarters in Germany. The Business Units Analyzing & Testing, Grinding & Dispersing and Pumps & Systems represent customized solutions at the highest level. More than 3,800 employees in 36 countries and a worldwide sales and service network ensure customer proximity and competent service.

Our performance standards are high. We promise our customers Proven Excellence – exceptional performance in everything we do, proven time and again since 1873.

When it comes to Thermal Analysis, Calorimetry (adiabatic & reaction), the determination of Thermophysical Properties, Rheology and Fire Testing, NETZSCH has it covered. Our 50 years of applications experience, broad state-of-the-art product line and comprehensive service offerings ensure that our solutions will not only meet your every requirement but also exceed your every expectation.

Proven Excellence.

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