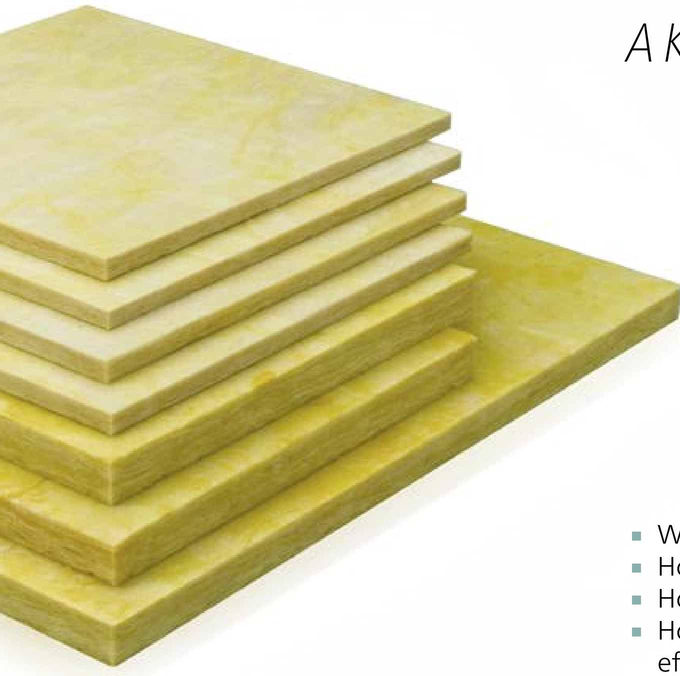
NETZSCH
Proven Excellence.

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

Based on ASTM C518, ASTM C1784, 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

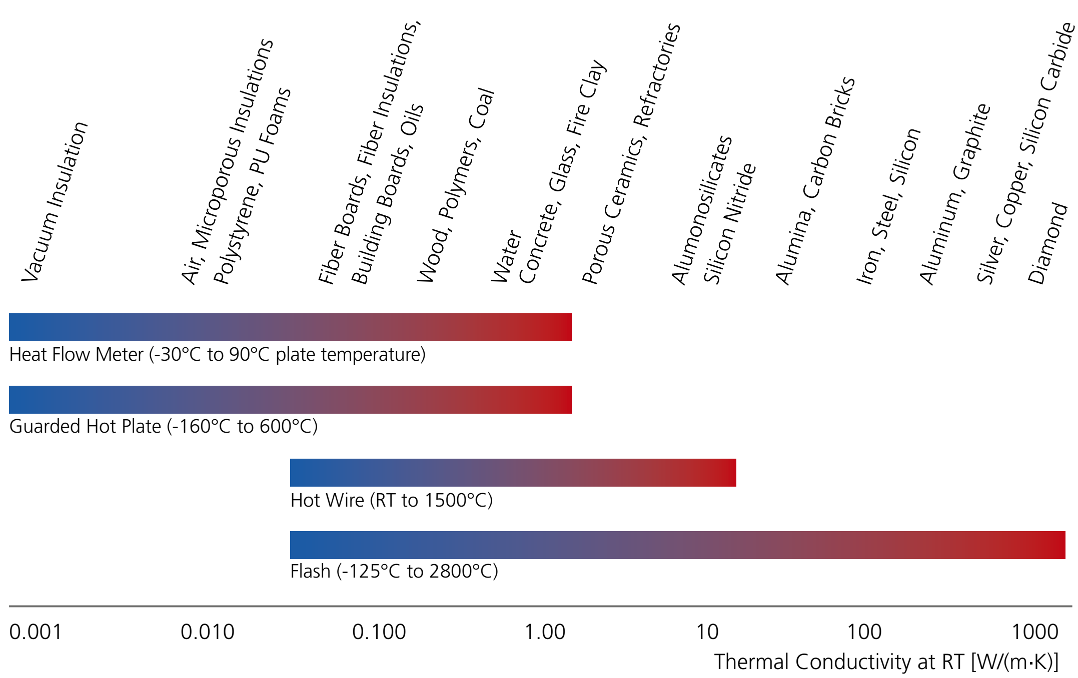
THERMAL CONDUCTIVITY

- What is the heating/cooling load of a building?
- How does this change with the weather and how can I improve it?
- How can I improve the heat transfer from an electronic component?
- How do I 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 insulation or a vacuum insulation panel, NETZSCH stands out with various types of heat flow meters (HFM) for diverse sample dimensions and temperature ranges.

The HFM *Lambda* Series is based on various relevant standards, e.g., ASTM C518, ASTM C1784*, ISO 8301, JIS A1412, DIN EN 12664* and DIN EN 12667.



* not HFM 446 *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 drop to measure heat flowing through the specimen. The sample thickness (L) corresponds to the actual sample dimension or to match the desired thickness of a compressible sample. 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 a thermal equilibrium, the test is done. The heat flux transducer output is calibrated with a standard. For the calculation of the thermal conductivity (λ) the average heat flux and the thermal resistance (R) is 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.

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

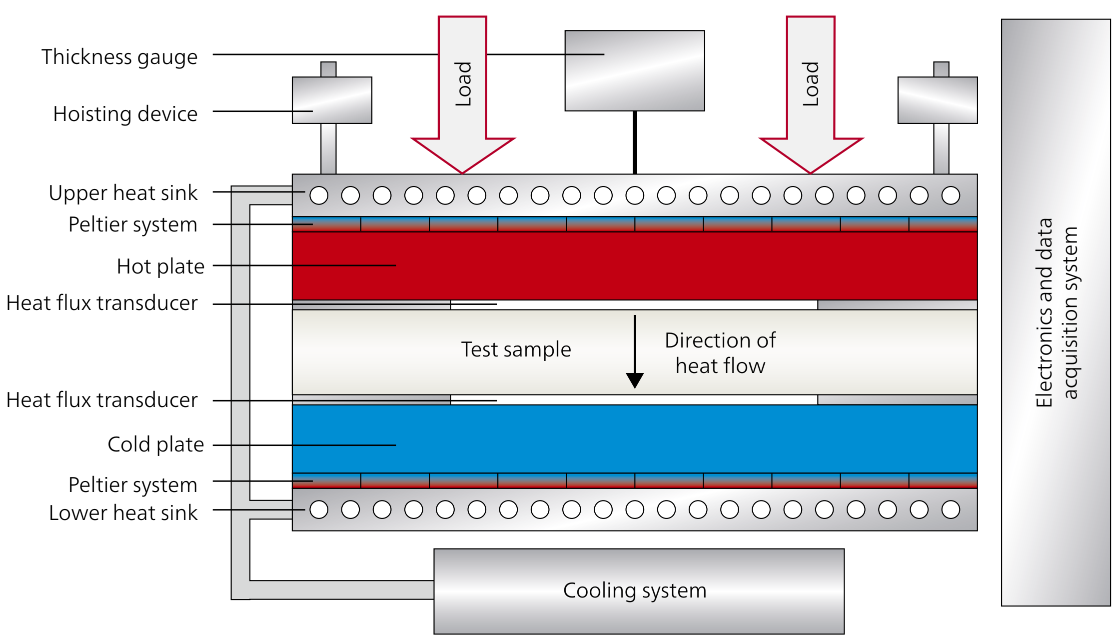
λ in SI unit: [W/(m·K)] or British Thermal Units: [Btu in/(h·ft²·°F)]

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

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. It performs tests according to ASTM C518, ASTM C1784*, ISO 8301, JIS A1412, DIN EN 12664* and DIN EN 12667.

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 user interface of 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. Signals from the transducers are electronically coupled to account for most edge losses from the specimen. Three type K thermocouples on each transducer for ΔT determination are distributed in the center, left and right side. In accordance with the European standards for HFM, they can be selected and read.

equipped with great features

HFM 446 *Lambda Large*

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).

SMARTMODE

VEARIOUS SAMPLE GEOMETRIES

HIGH PRECISION & ACCURACY

ADJUSTABLE TO NON-PARALLEL SPECIMEN FACES

EASY TO USE

$\lambda_{90/90}$

IN COMPLIANCE WITH STANDARDS

AUTOMATED OPERATION

QA DOCUMENTATION

FULLY SELF CONTAINED

NO COMPUTER REQUIRED

VARIABLE EXTERNAL LOAD

THICKNESS DETERMINATION

PRINTER OUTPUT

C_p MEASUREMENT

EXTENDABLE TO LOWER THERMAL RESISTANCES

WIZARDS & METHODS

The λ Solution

Fast sample change without affecting the plate temperatures

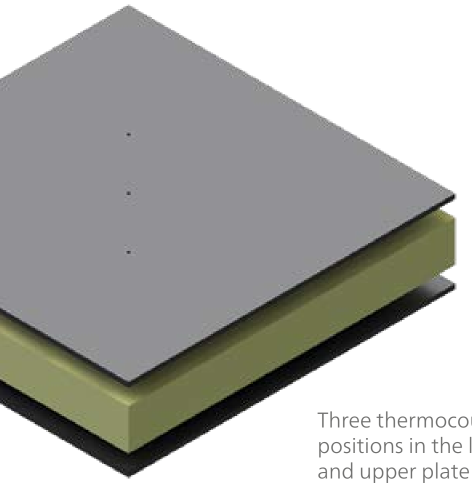
Peltier Temperature Control for Hot and Cold Plate

The plate temperatures are individually controlled by bidirectional heating/cooling Peltier systems, coupled with a closed loop fluid flow supplied by a chiller or any constant temperature recirculating system. The high-output Peltier elements accomplish thermal equilibrium and data sets within a short time – a productivity increase for your laboratory.

For the HFM 446 *Lambda Large*, the chiller is set up that its temperature corresponds to the specimen mean temperature.

Motorized Furnace Door and Plate Movement

The plates of the HFM 446 *Lambda Small* and *Medium* can be opened just slightly at the end of a test. For the next test, change of specimens can 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.



Three thermocouple positions in the lower and upper plate

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

The density of compressible materials can be varied and the resulting change in thermal conductivity measured

Variable External Load – Density Control of Compressible Specimens

The *Lambda* precisely controls the load exerted by the plates on the specimen, allowing the operator to specify contact pressure for the test (up to 854 N (HFM 446 *Lambda Small*) and 1930 N (HFM 446 *Lambda Medium* and *Large*) on the full-size specimen). This enables a control of the thickness, and thus density, of compressible materials.

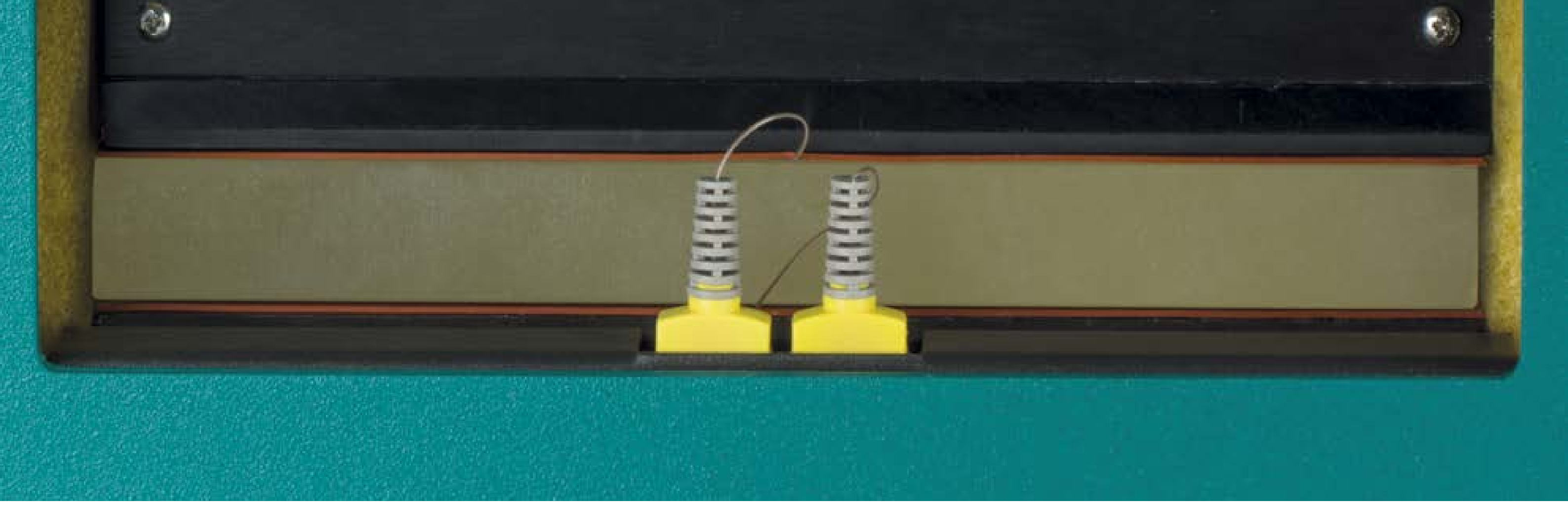
This feature also ensures that the plates make intimate contact with the specimen across the entire surface in order to produce a minimal and uniform contact resistance – two necessary requirements for obtaining reproducible thermal conductivity results.

Integrated Thickness Measurement

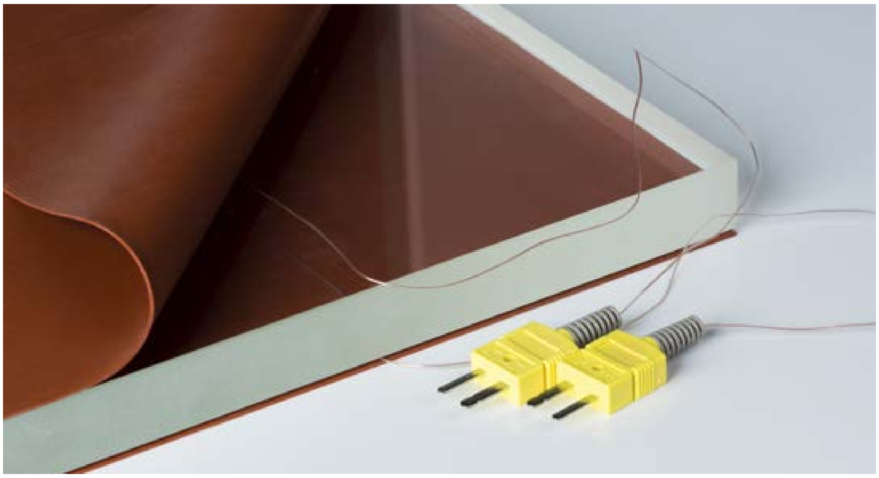
The HFM 446 *Lambda* Series comes with an integrated µm-resolution transducer, allowing the measurement of the specimen's actual thickness within a few seconds. On the upper plate, a two-axis inclinometer is integrated. The construction allows for many degrees of freedom specifically for inclined and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

Measuring frame for loosely filled material

Precise control regulates thickness and density of compressible materials



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



Thermocouples can be placed in the specimen's center

Improved Measurement Precision for Rigid Specimens with Low Thermal Resistances

The HFM 446 *Lambda* Series can be equipped with an optional instrumentation kit* that extends its range to lower thermal resistances (down to 0.02 $(m^2 \cdot K)/W$) like concrete, wood products, brick, etc.; maximum specimen thickness amounts to 50 mm.

The optional kit includes thin, compressible pads for use at both interfaces, and auxiliary thermocouples to be placed on both surfaces of the specimen. This increases the temperature accuracy – especially for applications which require an enhanced temperature sensing. Customer-specific configurations like air gaps can now be reliably tested.

* For HFM 446 *Lambda Large* on request

The instrument is delivered calibrated and a reference specimen is optionally included to use for verification. There is no need for calibrating the thermocouples. Of course, the list of available reference materials can be extended by the user and easily selected.

ACCESSORIES *AND MORE*

Pre-calibrated with Certified Reference Materials

The HFM system is delivered calibrated with a NIST-certified or IRRM reference standard of known thermal conductivity. This establishes the precise correlation between the signal output of the transducers and the actual heat flow. Thermal conductivity and thermal resistance are calculated once the user-defined equilibrium criteria are met. Of course, additional reference materials can be used. For both reference specimens, 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)

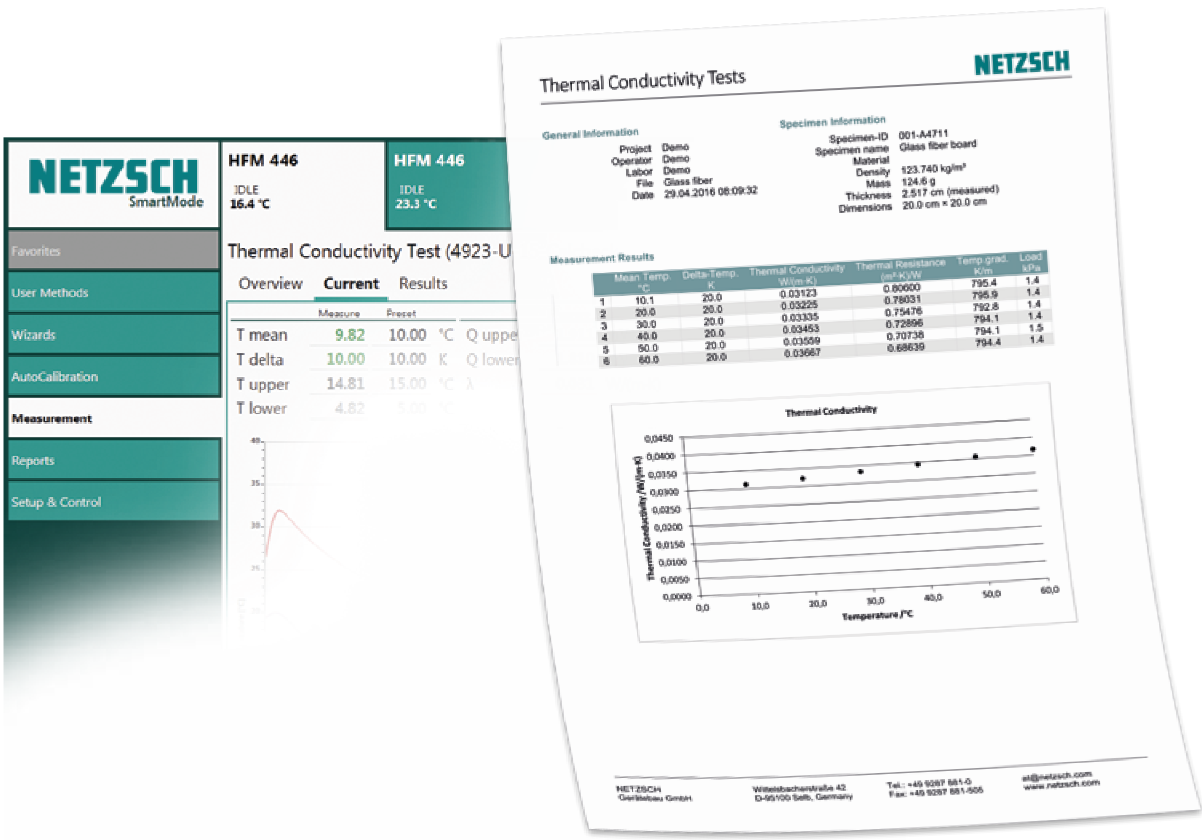
Best Test Condition with Reduced Risk of Condensation

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

The HFM 446 *Lambda Small* and *Medium* allow for the measurement of 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

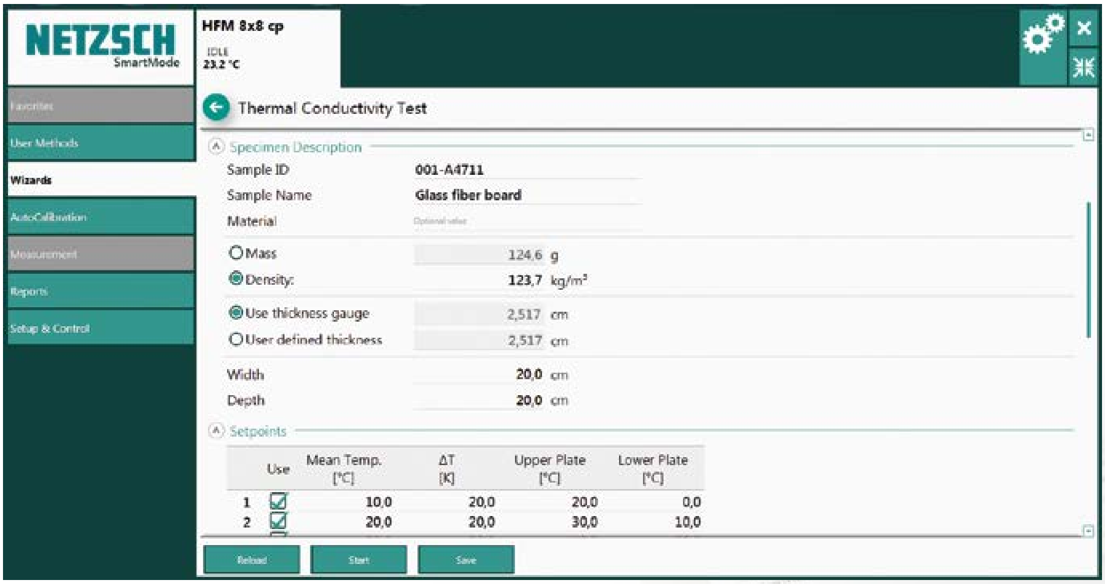
SmartMode is the user-friendly, smoothly running interface of the HFM *Proteus*® software. It is characterized by a logical structure which quickly gives a clear overview of the current measurement status and provides various report and export possibilities. Data is continuously acquired, processed and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

Calibration in Next to no Time

For calibration purposes, the thermal conductivity values of the most common certified reference materials, such as 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 10 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" if they are used frequently.



Printout of the results obtained by the integrated printer

Complete QA Documentation – Just a Click Away

The button “Report” 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” button exports data, graphs and results together into a single file. 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.

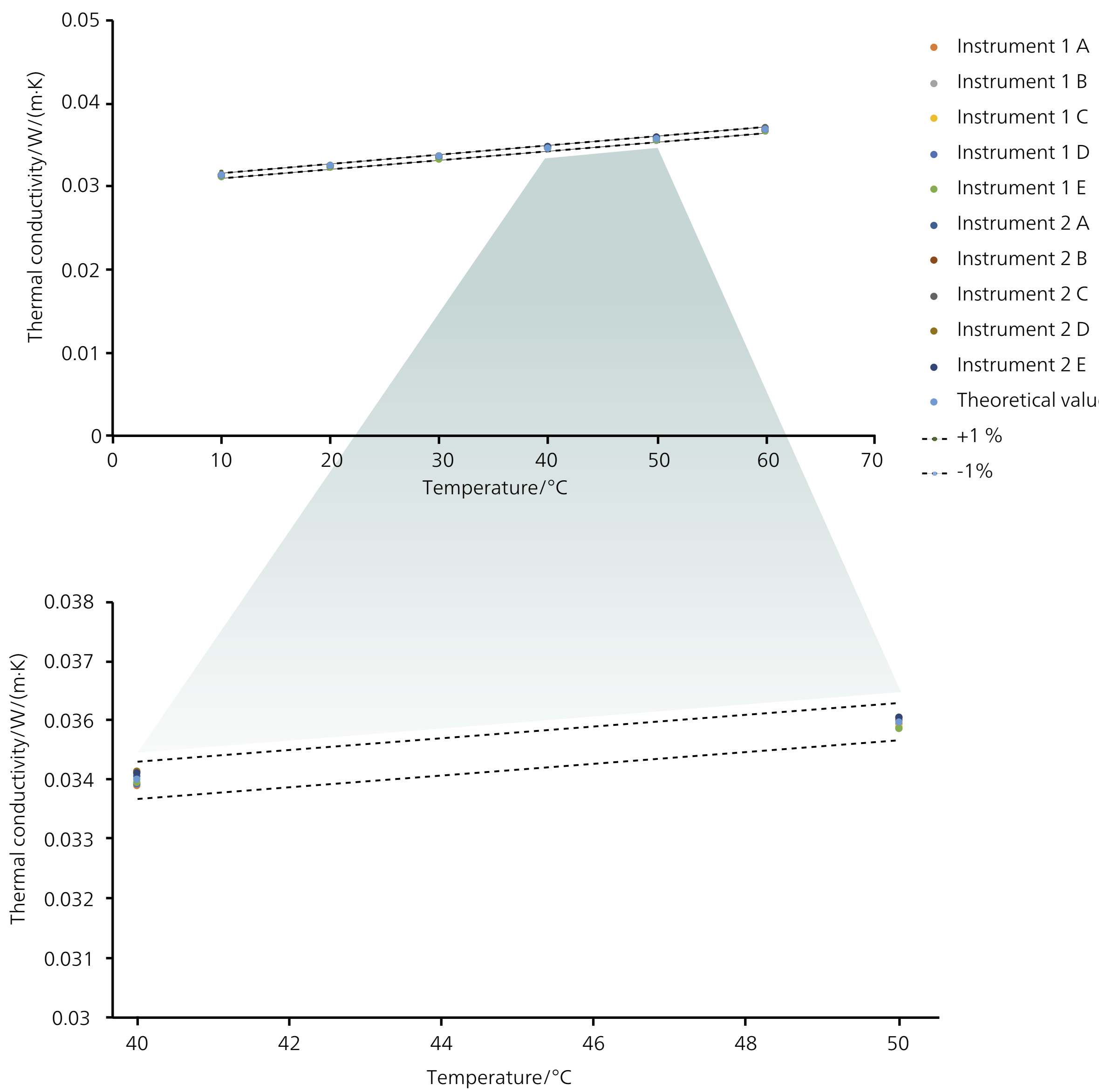
Setup & Control

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

Performance & Applications

Verification of the Performance

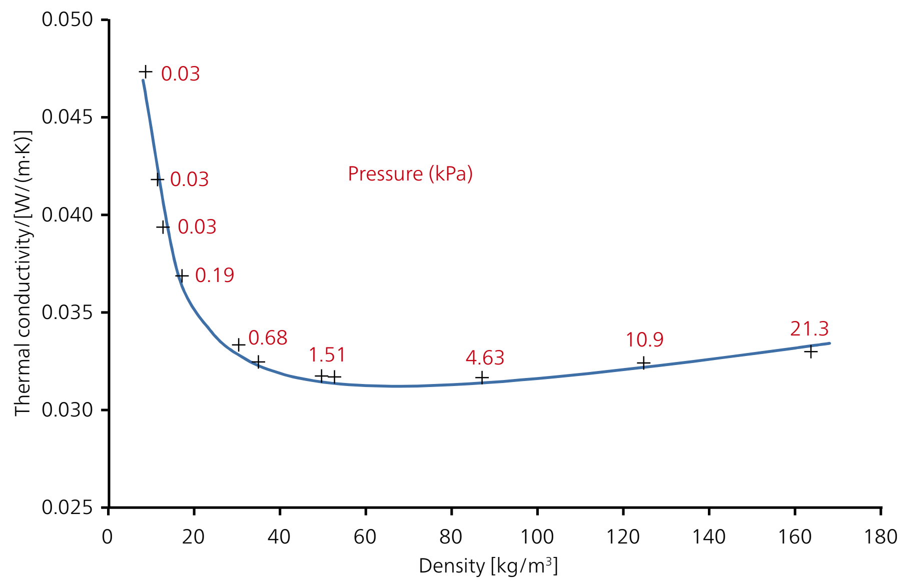
The performance of the HFM 446 *Lambda* Series is demonstrated by various measurements on the same reference material NIST SRM 1450 D. The tests were carried out on two different HFM 446 *Lambda Small* instruments and specimens five times between 10°C and 60°C. All measurement results are in very good agreement within ± 1% (dashed lines) with literature. The results also indicate the very good precision in accordance with ASTM C518.



Ten measurements on NIST SRM 1450 D performed with two instruments

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

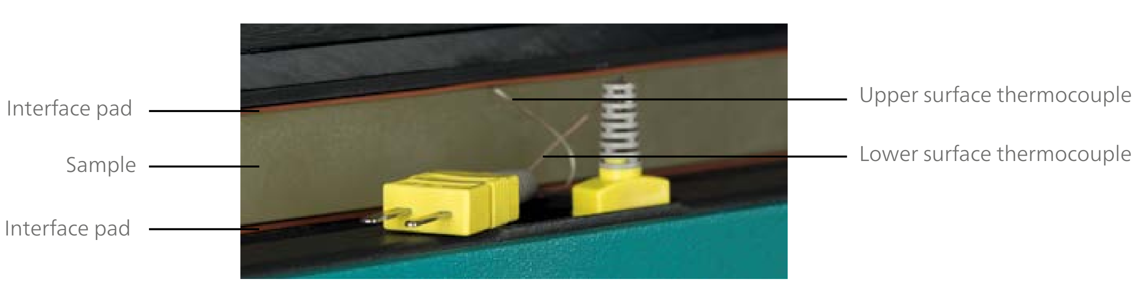
With the "Variable Load" feature, the density-conductivity correlation of compressible materials can be investigated. The case study presented here validates the expected multi-mode heat transfer within glass-fiber insulations. While the specimen is progressively compressed with an increasing load, represented 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.



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

The use of the instrumentation kit is crucial for low-resistivity materials. Test results on three types of concrete specimen demonstrate excellent agreement with the well-established Guarded Hot Plate method.
For thermal conductivity between 1.2 to 1.9 W/(m·K), the differences ranged from 2% to 4%.

Specimen	Thickness [mm]	Density [kg/m³]	Mean temperature [°C]	Thermal conductivity [W/(m·K)]	Thermal resistance [m²·K/W]
A1, A2 (GHP)	51.4	2297	25.2	1.76	0.0292
A1 (HFM)	51.7	2298	23.4	1.92	0.0269
A2 (HFM)	51.1	2296	23.8	1.69	0.0303
A1, A2 (average HFM)	51.4	2297	23.6	1.80	0.0286



C_p Measurement

The NETZSCH HFM 446 *Lambda* measures specific heat capacity (c_p) by heating the sample on a step-by-step basis while the two plates are maintained precisely at the same temperature. At each step, the total heat entering or leaving the specimen is portrayed as the integral of the heat-flux sensor signal. Thereby, the specific heat capacity of the plates also has an effect; its contribution is of course also taken into consideration.

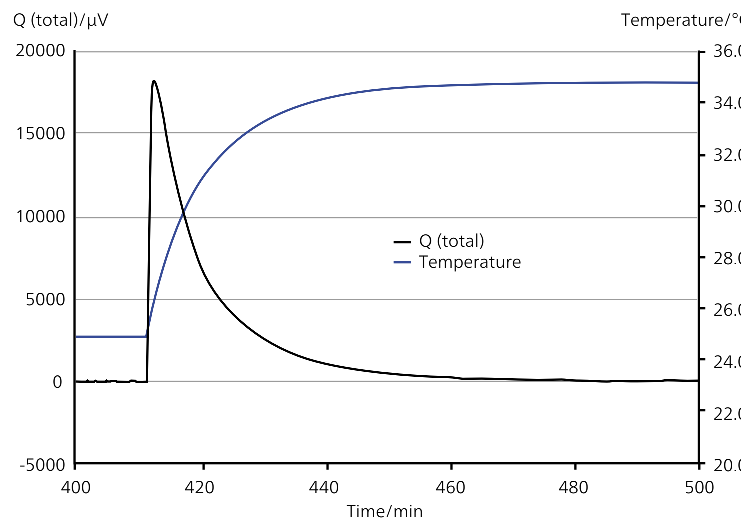
Specific Heat Capacity of a PU Foam

The upper plot shows the raw data results (with baseline corrected) used for determining the c_p of a PU foam. The curve represents the total heat flow meter output versus time for a heating step between 25°C and 35°C. After equilibration, both plates were heated to 35°C. The resulting combined heat flow at the upper and lower plate amounts to the total heat consumption required to heat the sample. Based on the integrated peak, the specific heat capacity can be determined at a mean temperature of 30°C.

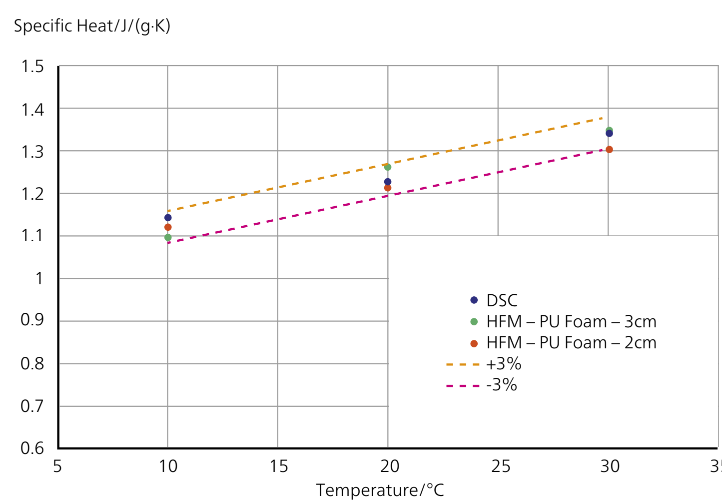
The lower plot depicts such tests on a PU foam between 10°C and 30°C in steps of 10 K. In addition to the resulting specific heat capacity, the plot also shows the results for the same material obtained by means of differential scanning calorimetry (DSC). The sample mass for the DSC test amounted to 10 mg; for the HFM tests, the sample masses were 38 g and 51 g, respectively.

The differences between the DSC and HFM results are less than 3%, which is within the stated uncertainty for the instruments and homogeneity of the material.

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.



Temperature development and heat flow meter output during a transient measurement of the specific heat capacity of a PU foam.



Specific heat capacity of a PU foam measured with the HFM 446 *Lambda* and NETZSCH DSC 204 ***F1*** *Phoenix*®. Results of several tests are shown; sample thicknesses for the tests were 2 cm and 3 cm, respectively.

Technical Specifications

HFM 446 *Lambda* Series	
Standards	ASTM C518, ASTM C1784*, ISO 8301, JIS A1412, DIN EN 12667, DIN EN 12664*
Type	Stand-alone, with integrated printer
Air-tight system	Sample compartment with possibility to introduce purge gas
Motorized plate	Yes
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) Lambda 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: 0.5% ■ Reproducibility: ± 0.5% → All performance data is verified with NIST SRM 1450 D (thickness 2.5 cm)
Plate temperature range	-20°C to 90°C, optional for the HFM 446 *Medium*: -30° to 90°C
Transducer metering	■ *Small*: 102 mm x 102 mm ■ *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	Operator-actuated plate opening for fast sample change, quick return to setpoint
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 10
Specimen size	■ *Small*: 203 mm x 203 mm ■ *Medium*: 305 mm x 305 mm ■ *Large*: 611 mm x 611 mm
Specimen thickness (max.)	■ *Small*: 51 mm ■ *Medium*: 105 mm ■ *Large*: 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) Precise load control and possibility to vary density of compressible materials; contact pressure calculated by software based on load sensor signal
Thickness determination	■ 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 instrument parameters, user-defined parameters, C_p determination, etc. ■ Storage and restoration of calibration and measurement files ■ Plot of plate/mean temperatures and thermal conductivity values ■ Monitoring of heat flux transducer signal

* not HFM 446 *Large*
*** Please note: In the very low thermal conductivity range, precision 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 3,700 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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