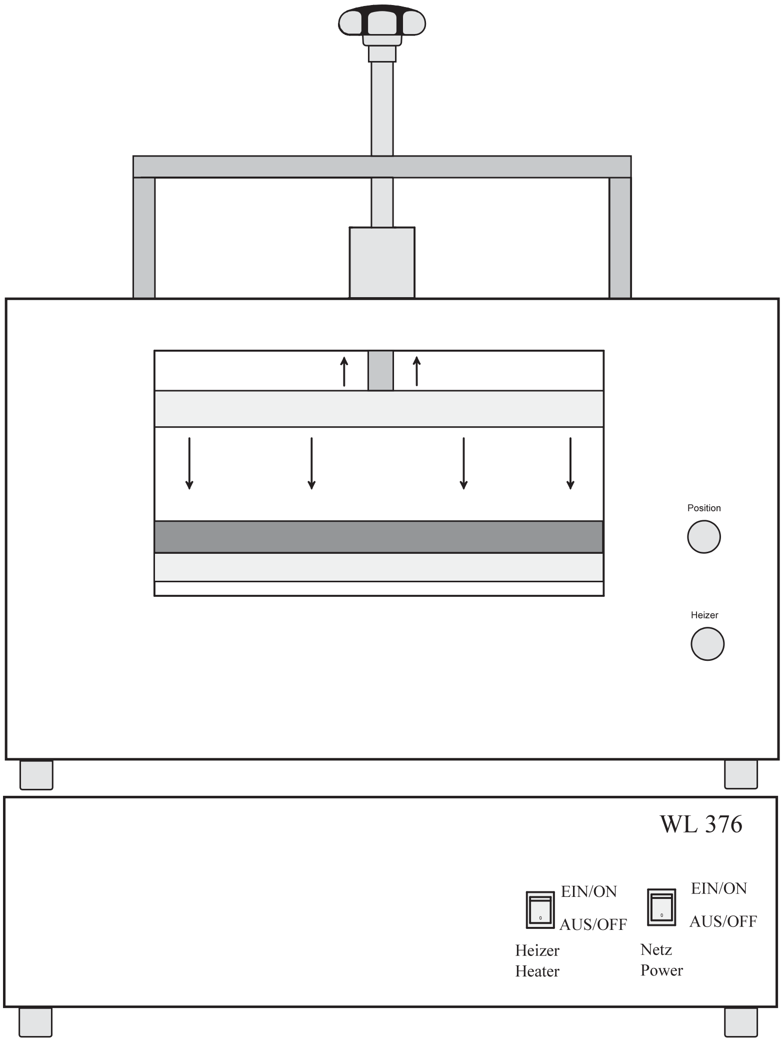
Experiment Instructions

WL 376

Thermal Conductivity
of Building Materials

WL 376 THERMAL CONDUCTIVITY OF BUILDING MATERIALS



Experiment Instructions

Please read and follow the safety regulations before the first installation!

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1 Introduction

In building physics, it is important to determine the quantity of heat that passes through a wall.

This is known as heat transfer and it primarily occurs in three ways:

- **Conduction** in solid or in static liquid or gaseous bodies.
- **Convection** between a solid and a flowing liquid or gaseous medium.
- **Radiation**, which occurs without a physical carrier.

This unit allows fundamental laws and variables relating to **thermal conduction** in solid bodies to be determined experimentally.

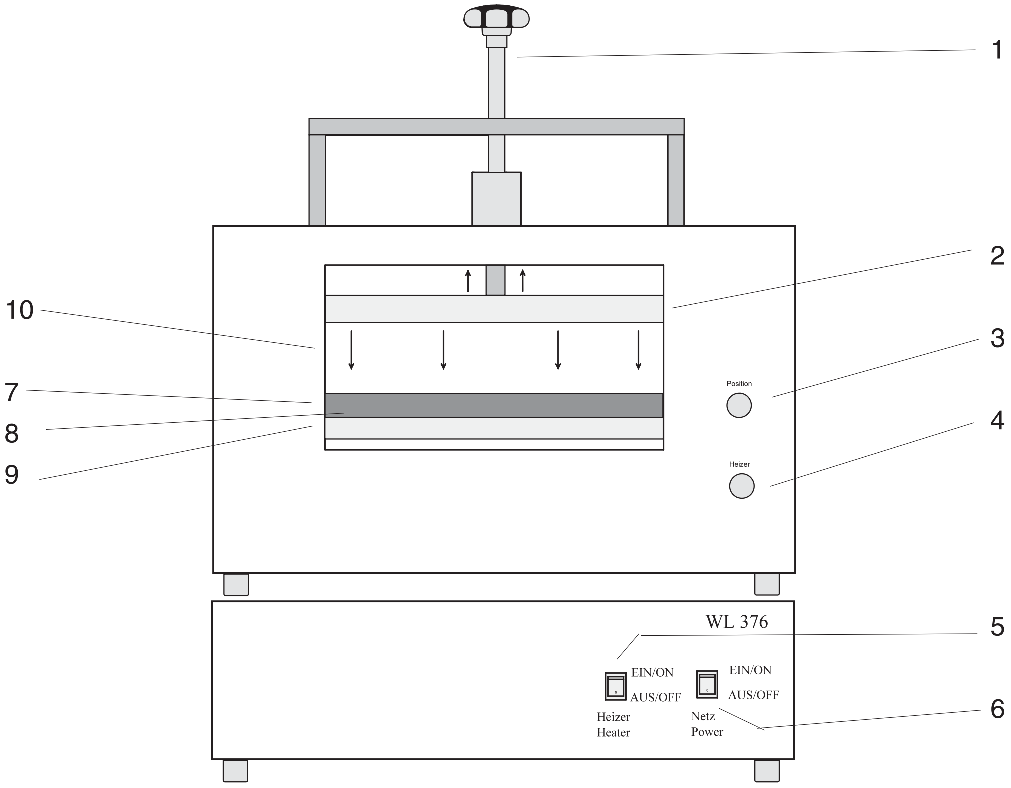
The unit is specially designed for materials that do not conduct electricity and have low thermal conductivity.
It is not suitable for metals.

It can also be used to look in more detail at problems with materials, e.g. energy savings from insulation against cold and heat or the influence of materials on energy balances.

The table-top **WL 376 Thermal conductivity of materials experimental unit** can be used to perform experiments with various materials by installing different specimens.

2 Unit description

2.1 Equipment layout



1 - Pressing spindle
2 - Hot plate
3 - Pressing pressure control lamp
4 - Heater control lamp
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7 - Cold plate
8 - Heat flow sensor
9 - Cooler
10 - Chamber for specimens

Rear of unit

- Mains supply
- PC interface
- Cooling water inlet and outlet

Fig. 2.1 View of WL 376 unit

2.2 Construction of cooling plate

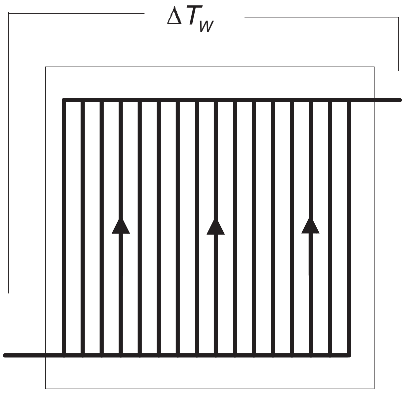


Fig. 2.2 Normal cooling water channel arrangement

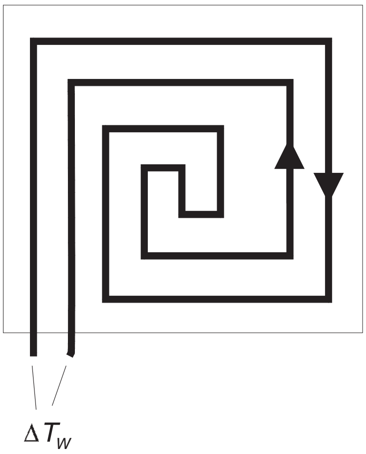


Fig. 2.3 Figure Cooling water channel arrangement on WL 376

As shown in Figure 2.2, with the normal arrangement of cooling water channels the ΔT_w must be very small in order to achieve an even temperature distribution.

The arrangement of the cooling channels in the WL 376 (Fig. 2.3) allows an even temperature distribution to be achieved at a larger ΔT_w. This means that temperatures can be set on the cold plate that are significantly higher than the cooling water temperature. This allows reproducible temperature gradients for the specimen, even with fluctuating cooling water temperatures.

2.3 Commissioning

Note: The unit should only be operated in conjunction with a PC. Before the WL 376 can be commissioned, the PC data acquisition card should be fitted in a PC and the associated software installed (see section 2.3).

Before commissioning, the experimental instructions must be read carefully and every participant in experiments should be instructed in proper handling of the unit.

1 Place the unit on a stable, flat surface.

2 Connect the mains cable supplied to the connector on the rear of the unit and connect it to the mains. The connection for the PC data acquisition card is also located on the rear of the unit. (See section 2.3)

3 Connect the water supply. First of all, connect a hose for the incoming water and a hose for the outgoing water on the rear of the unit. An outlet must be available for the outgoing water.

4 The cooling slots may not be kept closed or sealed and the unit may not be set up in such a way as to prevent adequate air circulation.

5 First of all, switch on the unit at the master switch (5) and then turn on the PC and start the software.

6 Open the specimen chamber by unscrewing the cover.

7 Place a specimen in the specimen chamber (9). To do this, loosen the pressing spindle (1) and raise the heating plate. Now place the specimen to be examined onto the cooling plate through the opening on the unit (9) and lower the heating plate again. Tightening the pressing spindle presses the specimen onto the heating and cooling plate with a defined pressure. This ensures a reproducible heat contact. The correct pressing force has been reached when the green lamp (3) on the front of the unit lights up.
Once the lamp is lit, the pressing spindle should be tightened by a further half turn.

8 Close the cover (attach with 4 nuts)

9 Ensure that the hose for the outgoing water ends in the outlet, then turn up the water supply for cooling.

10 Manually open the valve in the software
Set the optimum cooling water flow of approx. 1.2 - 2 l/min by gauging the capacity.

11 Now turn on the heater (6) on the front of the unit.

12 Set the setpoints for the cold and hot plates (see section 5.3.2).

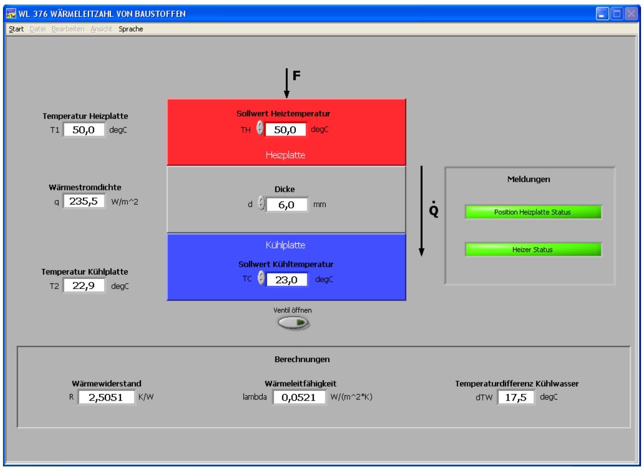
The experimental system is now ready for operation and the experiments can begin.

2.4 Data acquisition and control

The unit is equipped with PC data acquisition for control, regulation and automatic registration of measured values. This allows convenient evaluation of the measured values.

2.4.1 Installation of the software

To insert the card, open the computer. Fit the PCI card in a free PCI slot and close the computer again.



Temperatur Heizplatte
T1 50,0 degC

Sollwert Heiztemperatur
TH 50,0 degC

Wärmestromdichte
q 235,5 W/m^2

Dicke
d 6,0 mm

Temperatur Kühlplatte
T2 22,9 degC

Sollwert Kühltemperatur
TC 23,0 degC

Berechnungen

Wärmewiderstand
R 2,5051 K/W

Wärmeleitfähigkeit
lambda 0,0521 W/(m^2*K)

Temperaturdifferenz Kühlwasser
dTW 17,5 degC

Fig. 2.4 System diagram

Fig. 2.5 Menu

- Turn on the PC.
- Insert the G.U.N.T. installation CD.

- When Windows is started, the card is automatically detected and installed. The installation dialog then follows.
- To install the software, open WINDOWS EXPLORER and select the CD-ROM drive.

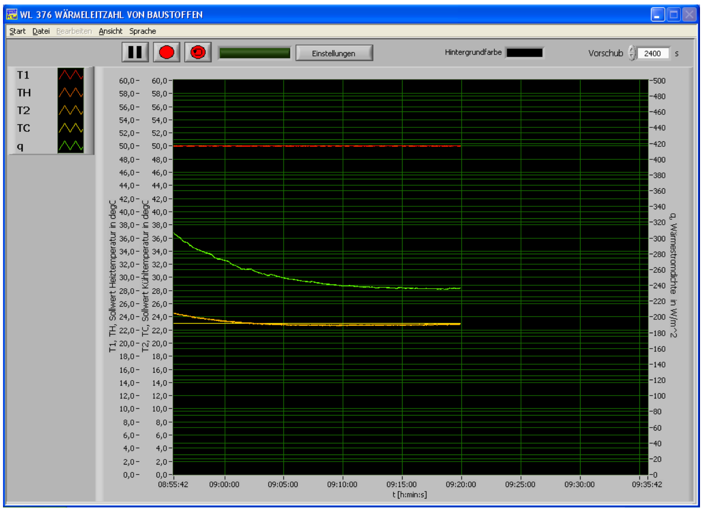


Fig. 2.6 Time elapsed

- Open the subdirectory **\installer**.
- Run the file **setup.exe** and follow the installation instructions on screen.

2.4.2 Starting the software

- Before the computer is switched on, the experimental unit must be connected to a power supply!
- Start Windows
- After installation, the program can be opened by selecting “Start - All Programs - G.U.N.T. - WL 376". From the main window that opens up, you can use the keys (1) to open further windows.

2.4.3 Start window

After the software is started, the main screen is displayed. From here, you can use the

Start (1) button to reach the individual sub-menus. You can use File (2) to create, load and save measured value files. View (4) is used to change the axis assignment in charts. Under Language (5), you can choose between English, German, Spanish and French.

System diagram allows you to enter target temperatures for the cold and hot plates and the material thickness. It also displays all data relevant to the process (e.g. heat flow density and thermal conductivity).

The switch for manually opening the solenoid valve (Open valve) is also located here.

2.4.4 Time elapsed

In the Time elapsed menu, measured values can be recorded individually or continuously.

Here, the measured values (temperature, volumetric flow and luminous intensity) are plotted over time.

The Settings option can be used to enter the measuring time and the number of measurements.

2.4.5 Controller

On this unit, a software controller is completely responsible for control operations. The controller parameters are fixed settings. They are optimised for all materials supplied.

3 Safety instructions

3.1 Hazards to life and limb

The following points must be observed in terms of work safety when using the WL 376 Thermal conductivity in construction materials experimental unit:

- **DANGER! Take care when opening the unit and working on all other electrical circuits.** There is a risk of electric shock. Make sure the mains connector is disconnected first. Work should only be carried out by specialist personnel.

- **DANGER! Do not touch hot surfaces and fittings.** There is a risk of burns. Always allow the unit to cool down first. Before changing the specimens, they should be allowed to cool for a few minutes. Always use gloves or a cloth when replacing the specimens.

3.2 Hazards for equipment and function

- **CAUTION!**Keep the ventilation slots on the side of the unit clear to prevent overheating of the measuring and control equipment.

4 Theoretical principles

4.1 Steady state thermal conduction

Thermal conduction is the molecular transfer of heat in solid, liquid and gaseous media under the influence of a temperature difference. Permanently maintaining heat transfer by supplying heat is the most common technical case of **steady state thermal conduction**, e.g. in heat exchangers.

The quantity of heat Q flows in a steady state through the cross-section of a solid body (Fig. 4.1) for time t in accordance with Fourier's Law, whereby the cross sectional area is significantly greater than the peripheral area.

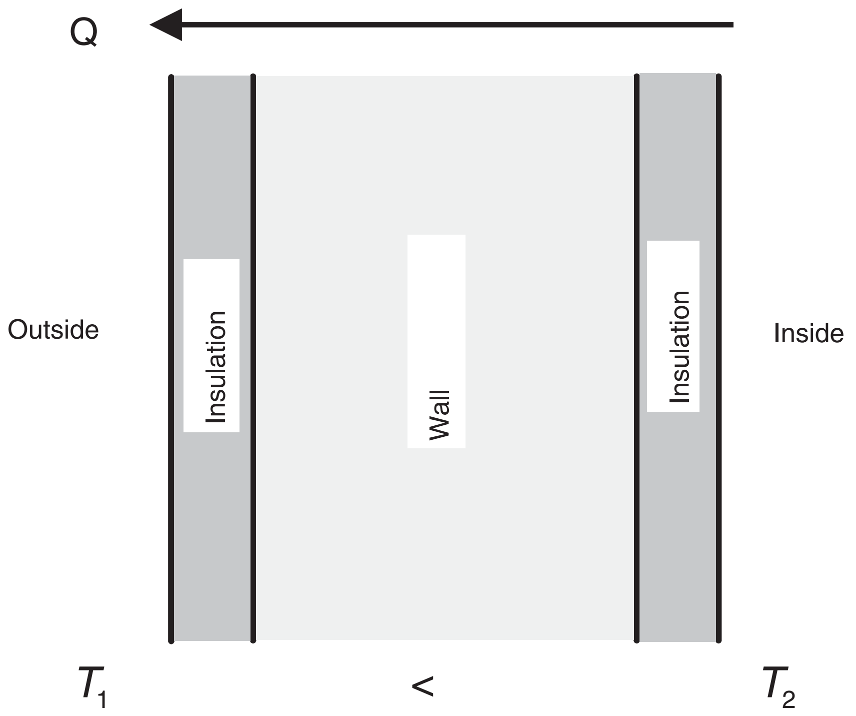


Fig. 4.1 Heat transfer through a wall

The **heat flow** $\dot{Q}$ due to thermal conduction is described by the following equation:

$$\dot{Q} = -\lambda \cdot A \cdot \frac{d\vartheta}{dx} \qquad (4.1)$$

Here, λ is the **thermal conductivity** of the material the heat is flowing through, ϑ is the **temperature**, $A = 0{,}046\ \mathrm{m}^2$ is the isothermic **area** and the **temperature gradient** $\frac{d\vartheta}{dx}$ in the direction of heat flow.

The calculation assumes that there is only a temperature difference in one direction and the temperature is constant in the planes vertical to it.

The heat flow relative to the area is known as the **heat flow density** $\dot{q}$:

$$\dot{q} = \frac{\dot{Q}}{A} \qquad (4.3)$$

Based on a material with a temperature independent thermal conductivity of λ and with the temperatures ϑ_1 and ϑ_2 as the surface temperatures, we obtain the following **heat flow density** $\dot{q}$:

$$\dot{q} = \frac{\lambda}{s} \cdot (\vartheta_1 - \vartheta_2) \qquad (4.4)$$

4.2 Thermal conductivity through a layer

Through a flat wall, equation 4.1 gives a heat flow of:

$$Q = -\lambda \cdot A \cdot t \cdot \frac{d\vartheta}{dx} \qquad (4.5)$$

At a constant cross section A and $dx = s$ this gives:

$$\dot{Q} = \frac{\lambda}{s} \cdot A \cdot (\vartheta_1 - \vartheta_2) \qquad (4.6)$$

4.2.1 Thermal conduction through flat wall with multiple layers

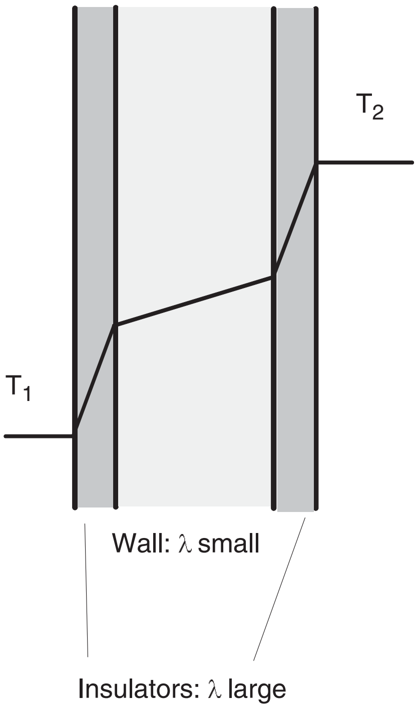


Fig. 4.2 Temperature curve for a typical wall construction

The heat flow is the same for each layer of a wall. Here:

1st layer: $\dot{Q} = \frac{\lambda_1}{s_1} \cdot A \cdot (\vartheta_1 - \vartheta_2)$

2nd layer: $\dot{Q} = \frac{\lambda_2}{s_2} \cdot A \cdot (\vartheta_2 - \vartheta_n)$

nth layer: $\dot{Q} = \frac{\lambda_n}{s_n} \cdot A \cdot (\vartheta_n - \vartheta_{n+1})$

Rearranging and adding the individual layer equations gives the desired heat flow resulting from the total temperature difference as follows:

$$\dot{Q} = \frac{A \cdot (\vartheta_1 - \vartheta_{n+1})}{\frac{s_1}{\lambda_1} + \frac{s_2}{\lambda_2} + \frac{s_n}{\lambda_n}} \qquad (4.7)$$

The summands in the equation (4.7) can be interchanged, signifying that the thermal resistance of a flat wall does not change if the layers are interchanged.

4.3 Thermal resistance

Based on Ohm’s Law, the thermal resistance is defined as follows:

$$\mathit{Thermal\,Resistance} = \frac{\mathit{Temperature\ Difference}}{\mathit{Heat\ Flow}}$$

This results in a thermal resistance of:

$$R = \frac{|\Delta t|}{\dot{Q}} \text{ in } \frac{K}{W} \tag{4.8}$$

This applies to all three types of heat transmission. In the case of thermal conductivity resistance for the single layer flat wall, the equation (4.8) gives:

$$R_1 = \frac{t_1 - t_2}{\dot{Q}} = \frac{\delta}{\lambda\, A} \tag{4.9}$$

For walls with multiple layers, the procedure is the same as for thermal conduction. The thermal resistance through multiple layer walls can thus be derived as follows:

$$R_{1ges} = \left(\frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{\delta_3}{\lambda_3}\right) \cdot \frac{1}{A} \tag{4.10}$$

If there are more than three layers, the equation is extended with the corresponding terms.

5 Experiments / Instructor

Didactic instructions and materials for the supervisor

5.1 Didactic remarks

- Use of the system in practical training

The experiments on the WL 376 are planned as practical investigations.

The unit can be conveniently used by a small group of 2 to 3 participants.

We have described and explained the suggested experiment in detail on the following pages. They also include the example solutions for the experiment, which you should work through yourself later.

We recommend that you completely perform and evaluate these experiments once yourself as an orientation.

This will allow you to become familiar with all the details so you can then have the experiments carried out on an independent basis.

For this purpose we have prepared worksheets, which provide the participants with instructions and guide them systematically through the experiment. You can photocopy or print out these worksheets in the required numbers.

If you hand out the following pages about the aims of the experiment, preparation and experimental method to the participants along with the worksheets, they will be able to perform and evaluate the experiments completely independently.

You can find the worksheets in the Participants section.

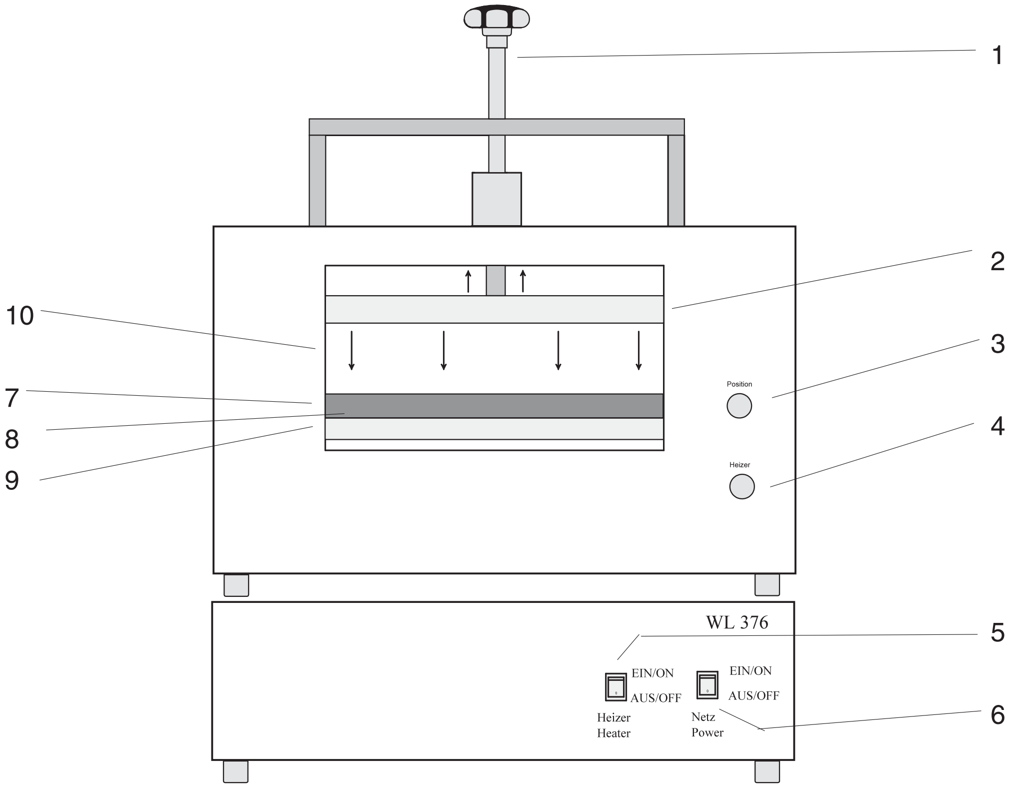
Before performing independent experiments, instruct all participants in the technology (safety instructions) and operation of the unit.

We of course assume that the necessary theoretical principles have been dealt with prior to performing the experiments.

- **Aim of experiment**

The aim of the experiment is to determine and compare the thermal conductivity λ of various materials (insulators) and plastics used in engineering.

5.2 Preparations for experiment



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6 - Heater ON/OFF
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8 - Heat flow sensor
9 - Cooler
10 - Chamber for specimens

Rear of unit
- Mains supply
- PC interface
- Cooling water inlet and outlet

Fig. 5.1 View of WL 376 unit

- Connect WL 376 to PC using the PC interface cable and turn on the PC.
- The WL 376 is controlled from a PC. The PC should be turned on before the unit itself and the software started.
- Set the flow (approx. 1-2 l/min)
- Turn on the main unit using the mains switch (5)
- Open the testing chamber by unscrewing the 4 knurled screws and removing the cover
- Insert the specimen in the testing chamber (9) and fix the specimen in place by lowering the heating plate (2) until the control lamp (3) lights up
- Close the testing chamber with the cover
- Set the data for the specimen and the setpoint temperatures using the software (see section 5.3.2 Experimental method)
- Turn on the heater on the base unit using the heating switch (6)

General information on experiments

The measured results listed should not be viewed as reference or calibration values for all conditions. Depending on the design of the individual components used and the experimental skills demonstrated, smaller or larger variations can occur.

5.3 Recording the coefficient of thermal conductivity

5.3.1 Aim

Recording the coefficient of thermal conductivity for different materials (cork, plaster, POM etc.)

5.3.2 Experimental method

The experiment is based on the DIN 52616 and DIN 52612 standards for “Determination of the thermal conductivity using heat flow plate equipment”.

Read section 5.2 “Preparations for experiment” before commencing the experiment.

Temperature selection:
The cooling temperature cannot be lower than the cold water temperature. To allow good control behaviour, the cooling temperature should be around 10°C higher than the cold water temperature. A large temperature difference between the cold and hot plates increases the measuring accuracy. However, particularly for plastics the temperature of the hot plate should not exceed 80°C, to prevent deformation or destruction of the specimen.

The setpoints for the cold and hot plate temperatures can be entered in the software. If the ambient conditions vary, the temperatures must also be adjusted so that the temperature difference remains almost constant.

The heater can provide a maximum temperature of 150°C. However, this temperature is not required for any of the experiments. To protect the specimen material and ensure a long service life, the heating temperature should be set in the range 40-80°C and the cooling temperature in the range 10-40°C. However, you should always bear in mind the fact that a high temperature difference between the cold and hot plates results in increased accuracy.

For this experiment, one of the 8 plates supplied is placed in the unit. After turning on the heater (6), the heating plate heats up.

The temperature increase can be monitored in the software. For a clearer representation, you should switch to the Time elapsed window (Fig. 5.2).

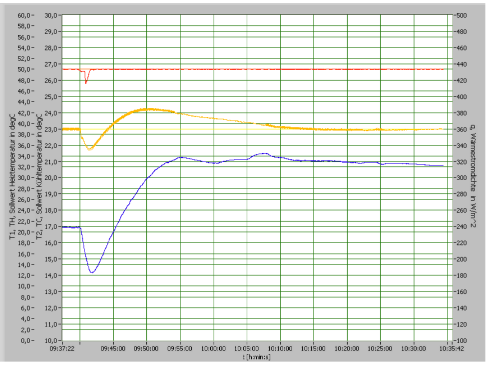


Fig. 5.2 Time elapsed example

To record the curve, the number of measured values and the measuring time can be selected under Settings in the Time elapsed window. These are then saved to a file in the folder GUNT.

In order to be able to record the measured values, you must wait until a steady state has been established, which can take between 60 and 120 minutes. The diagram shows the steady state after the settling phase, which is characterised by a slight overshoot.

The theoretical values can be found in the Appendix under Technical data.

5.3.3 Measured values

The measured values displayed after a steady state is reached are entered in the table. These will differ depending on the material. This experiment has been performed for the cork plate.

Material:	CORK	
T1	50	°C
T2	23	°C
q	238.5	$\frac{W}{m^2}$
R	2.4514	$\frac{K}{W}$
λ	0.0533	$\frac{W}{m \cdot K}$
$\lambda_{Theoretisch}$	0.04 – 0.06	$\frac{W}{m \cdot K}$
ΔT_W	17.6	K
d	6	mm

5.3.4 Evaluation

The value achieved for the thermal conductivity λ in the experiment corresponds closely to that stated in the literature. In general, greater variations between the measurement and the literature can occur. This can be attributed to the individual condition of the specimen. This is the area of application of a thermal conduction measuring device. This can be used to determine the actual thermal conductivity value of an individual material.

6 Worksheets for participants

Worksheets for participants

6.1 Comments

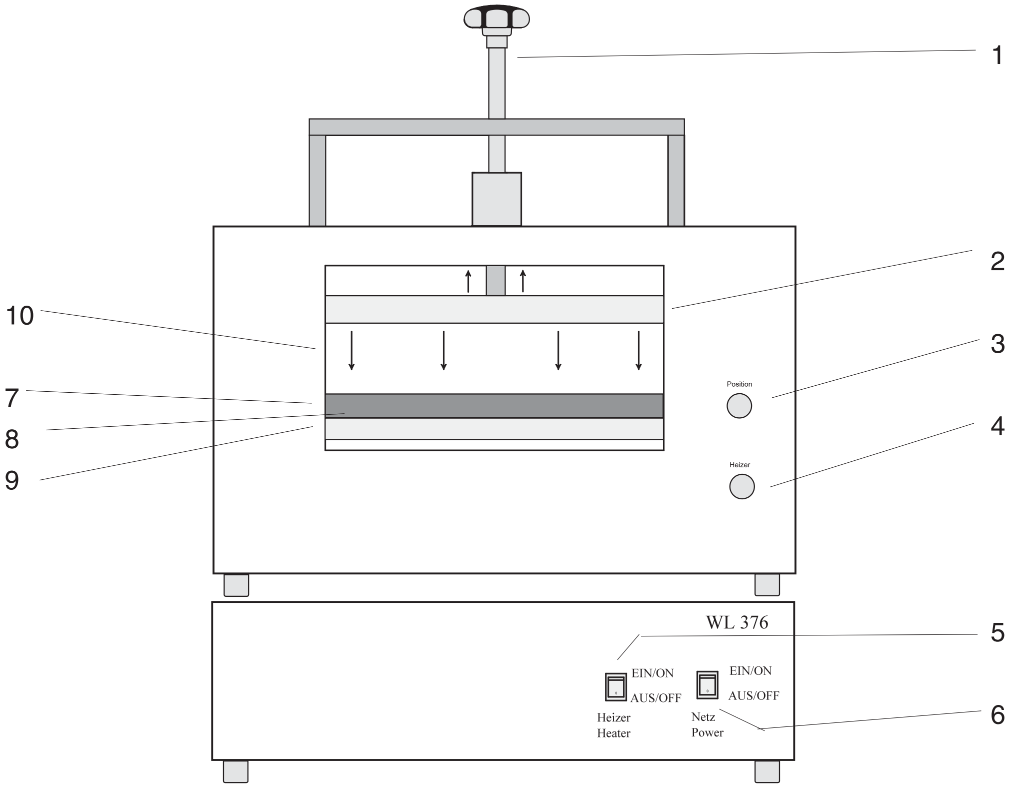
All experiments presented here should be carried out as student experiments.

The experiments are structured in such a way as to allow an insight into determination and comparison of the thermal conductivity of construction materials.

- **Aim of experiment**

The aim of the experiment is to determine and compare the thermal conductivity $\lambda$of various materials (insulators) and plastics used in engineering.

6.2 Preparations for experiment



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- Close the testing chamber with the cover
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- Turn on the heater on the base unit using the heating switch (6)

6.3 Recording the coefficient of thermal conductivity

6.3.1 Aim

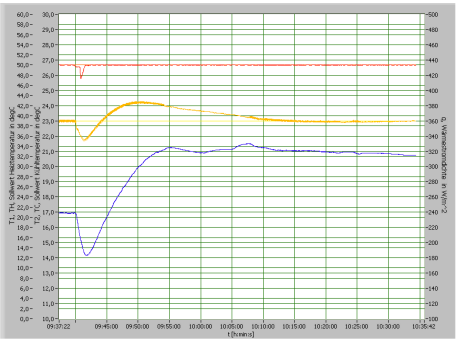
Comparison of coefficients of thermal conductivity for different materials (cork, plaster, POM etc.)

6.3.2 Experimental method

Read section 5.2 “Preparations for experiment” before commencing the experiment.

For this experiment, one of the 8 plates supplied is placed in the unit. After turning on the heater (6), the heating plate starts to heat up.

The temperature increase can be monitored in the software. For a clearer representation, you should switch to the Time elapsed window (Fig. 6.2).



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6.3.3 Measured values

The measured values displayed after a steady state is reached are entered in the table. These will differ depending on the material.

Material:		
T1		°C
T2		°C
q		$\frac{W}{m^2}$
R		$\frac{K}{W}$
λ		$\frac{W}{m \cdot K}$
$\lambda_{Theoretisch}$		$\frac{W}{m \cdot K}$
ΔT_W		K
d		mm

6.3.4 Evaluation

- Which material provides the best insulation effect?
- How does the thermal conductivity affect the energy balances?

7 Appendix

7.1 Technical data

Dimensions of experimental unit:

Weight:	approx. 50	kg
Height:	806	mm
Width:	750	mm
Depth:	580	mm

Dimensions of specimen chamber:

Specimen surface:	300 x 300	mm
Area of Transmission	A = 0,046	m^2
Height:	max. 50	mm

Silicon heating mat:

Power:	500	Watt
Temperature:	max. 170	°C

Temperature measurement:

Thermocouple, type Pt 100

Sensor plate:

Temperature range:	-20 - 85	°C
Calibration factor:	1 mV = approx. 3	W/m^2
Heat flow:	min. 20	W/m^2
	max. 500	W/m^2

Cooling:

Water temperature:	10-15	°C
Water volume:	1,2	l/min
Water pressure:	1 - 6	bar

Specimens:

Material: *Armaflex*

Coefficient of thermal conductivity λ:
0.036 - 0.040 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 19 mm

Material: *Chipboard*

Coefficient of thermal conductivity λ:
0.17 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 13 mm

Material: *PMMA*

Coefficient of thermal conductivity λ:
0.19 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 20 mm

Material: *Styrofoam*

Coefficient of thermal conductivity λ:
0.030 – 0.040 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 5 mm

Material: *PS*

Coefficient of thermal conductivity λ:
0.15 – 0.4 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 10 mm

Material: *POM*

Coefficient of thermal conductivity λ:

0.23 – 0.37 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 26 mm

Material: *Cork*

Coefficient of thermal conductivity λ:

0.04 – 0.06 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 6 mm

Material: *Plaster*

Coefficient of thermal conductivity λ:

0.21 $^{W}/_{mK}$

Dimensions: 300x300 mm

Thickness δ: 9 mm

Power supply

Voltage: 230 V/50 Hz, 1ph

Optional alternatives, see rating plate

Fuse: 6.3 A

Water connection

Outlet or floor drain

7.2 References

Walter Wagner, Wärmeübertragung [Heat transmission], Vogel Fachbuch / Kamprath-Reihe, 4., Revised edition. Würzburg 1993

Günter Cerbe, Hans-Joachim Hoffmann, Einführung in die Wärmelehre [Introduction to thermodynamics], Carl Hanser Verlag, 9., Improved edition, Munich, Vienna 1990

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