Damping temperature fluctuations using multiple-layered walls

Recording and evaluating with CASSY

Objects of the experiments

- Measuring the temperature as a function of time at a two layered probe switching the heat source periodically on and off.
- Observation of amplitude and phase shift in different depth of the multiple layered wall.
- Comparison of the temperature rise inside the heat measuring chamber by variation of the wall material

Basics

In spite of the outside temperature change between day and night a constant temperature inside rooms is desired. The radiation of the sun warms the external walls during daytime. The walls conduct the heat to the inside and then cool down again during night. These periodic fluctuations of temperature are characterized as a temperature "wave", which is described in terms of amplitude and period.

The experiment examines the situation with two-layered walls of building materials. In this experiment the house interior corresponds to the interior of the calorimetric chamber. The shining sun is represented by a halogen lamp directed to the measuring chamber. The change between day and night is simulated by periodically switching on and off of the halogen lamp.

The period is about a few minutes. During illumination (day) or cooling (night) the temperature change of the outside temperature is proportional to the temperature itself plus a constant:

$$\frac{\Delta \vartheta}{\Delta t} = a \cdot \vartheta + b \,.$$

The solution of this equation for the temperature as a function of time ϑ (t) is:

$$\vartheta(t) = \vartheta_{End} - \vartheta_{Diff} \cdot e^{-\frac{t}{\tau}}$$

with

ϑ_{End} : The maximum temperature during irradiation (heating up) respectively the resulting temperature after cooling (room temperature)

$\vartheta_{Diff} = \vartheta_{End} - \vartheta_{Start}$: Temperature difference

τ : Time constant.

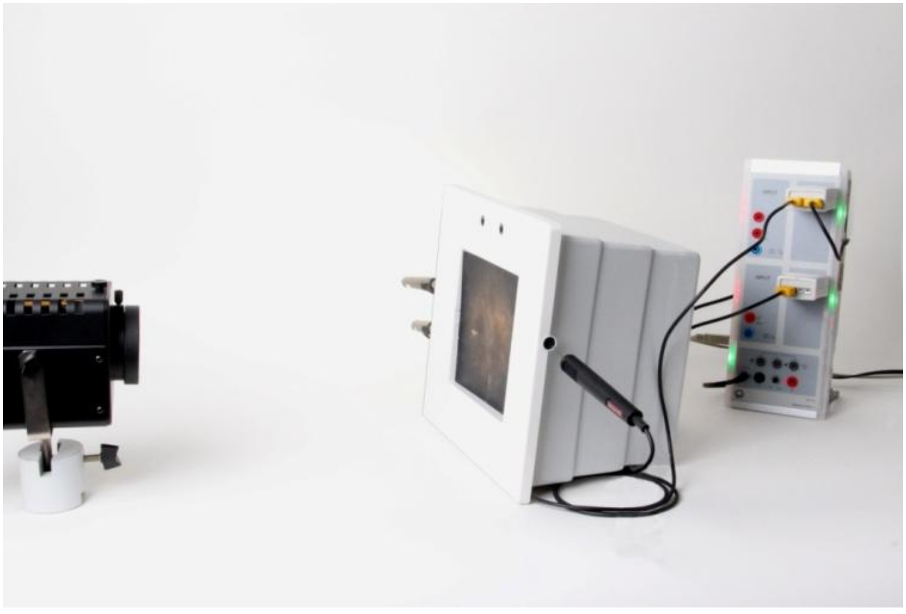

Figure 1. Simulation of change between day and night by periodical illumination

YS 2013-03

Apparatus

1 Calorimetric chamber....................................389 29
1 Building materials for calorimetric chamber ...389 30

1 Halogen lamp, 12 V, 50/100 W 450 64
1 Halogen bulb, 12 V/100 W, G6.35 ....450 63
1 Saddle base..300 11

1 Transformer 2 to 12 V; 120 W........................521 25

2 Connecting lead 32 A, 100 cm, black.............501 33

1 Sensor-CASSY 2 ....524 013
1 CASSY Lab 2...524 220
2 NiCr-Ni Adapter S, Type K............................524 0673
3 Temperature probe NiCr-Ni, 1.5 mm, Type K 529 676

1 PC with Windows XP/Vista/7/8

During illumination applies $\vartheta_{Diff} > 0$ and during cooling $\vartheta_{Diff} < 0$. Due to the switching of the radiating lamp the temperature of the outer wall is a periodic function of time. The temperatures between the two samples of building materials as well as inside the heat chamber change time-dependent. However these temperature waves are strongly damped in amplitude and shifted in phase with respect to the external temperature.

Experimental setup

- The experimental setup is shown in Figure 1. Prepare two building panels (Polystyrol and Rohacell) to form a "sandwich" and subsequent assembly into the calorimetric chamber:
- Insert the small contact plate made from aluminum into the circular recess of the polystyrene plate with thermal paste. The contact plate must be rotated in such a way, that the recess is located in direction of the groove.
- Apply thermal paste only on the contact plate!
- Now place carefully a thin blackened aluminum plate (Thickness: 0.3 mm) with the black side up on the polystyrene plate to avoid bending of the thin plate
- Repeat these steps for the other side, however, use an unpainted aluminum plate.
  Note: This unpainted aluminum plate separates the two samples of building materials during the tests.
- Now place carefully a second thin blackened aluminum plate (Thickness: 0.3 mm) with the black side up on a Rohacell plate to avoid bending of the thin plate
- Prepare the tip of the temperature probe by feeding it through a rubber stopper (diameter: 1.5 mm). Do not bend the tip. The rubber stopper avoids heat convection into the measuring chamber!
- Insert the polystyrene plate sandwich with the blackened side down into the calorimetric chamber. Keep attention that the ends of the groove show to the holes in the calorimetric chamber which allow the insert of the temperature sensors.
- Now insert the Rohacell plate with the blackened aluminum showing up onto the already inserted polystyrene sandwich in the calorimetric chamber.
- Keep attention that the pure aluminum plate is located between the polystyrene and Rohacell plates and that the holes to insert the temperature sensors are on opposite sites for the polysterene and Rohacell plate .
- Insert all three temperature sensors, one at the top the second between the two plates and the third at the bottom. If needed take the mounting hook for lifting plates
- Connect the temperature sensor to the Sensor-CASSY by using the NiCr-Ni adapter as shown in Figure 1.
- Carefully place the prepared heat measurement chamber perpendicular to the table and avoid the outstanding temperature sensors touching the table as well as being affected during experimental procedure (see Figure 1).
- Insert the lamp into the halogen lamp. Then connect the transformer as shown in Fig. 1 first. Do not switch on the transformer!
- Arrange the calorimetric chamber and the halogen lamp in such a way, that the halogen lamp will directly irradiate the blackened aluminum plate.

- Load settings in CASSY Lab 2.
- Switch on the transformer. Do not start the measurement
- Place the halogen lamp in a distance of approximately 1 m and adjust the light illuminating the entire black area without radiating the heat measuring chamber itself. During the test, observe the outside temperature.

Note: The outside temperature may not exceed 60 °C. Otherwise, turn off the transformer immediately and increase the distance between the measuring chamber and halogen lamp.

- The outdoor temperature ϑ_{A11} should be between 50 °C and 55 °C. After radiation for about 10 minutes and should change very slowly (< 1°C/min).
- Switch off the transformer and let the outside of the calorimetric chamber cool down to room temperature.

Experimental procedure

- Start Measurement with CASSY Lab 2 with and immediately switch on the transformer.
- Switch off after 10 to 12 minutes.
- Switch on the transformer again after the same period.
- Repeat this procedure of switching on and off several times.
- Stop the measurement with
- Switch off transformer.

Note: For disassembly the temperature sensors must be removed first. N tow he building panels can be lifted out with the mounting hook.

- Now insert the two building panels in the opposite sequence and repeat the experiment.

Observation

When illuminated, the outside temperature ϑ_{A11} quickly rises while the temperature ϑ_{A12} between the building panels and the temperature ϑ_{B11} inside the calorimetric chamber changes slowly.

After turning off the temperature ϑ_{A11} on the outside falls off quickly..

The outside temperature changes periodically within 12 minutes by about 25 ° C.

In contrast, the internal temperature will rise only a few degrees Celsius during the entire measurement (about 50 min).

Measurement examples

Figures 2 and 3 show two examples of measurements. There a plate of Rohacell (insulating) and a plate of polystyrene were used. The polystyrene plate has a significantly higher thermal conductivity than the Rohacell plate.

The outside temperature ϑ_{A11} (sawtooth-shaped curve with the greatest amplitude) was measured directly on the surface and is therefore largely independent of the sequence for the two building panels. By periodically switching on and off the light source a temperature wave is generated.

The smaller amplitude wave curve is the temperature ϑ_{A12} , measured between the two building panels. The amplitude attenuation is clearly seen in both cases.

The damping of the temperature wave during the passage through the two sheets extinguishes the temperature wave, showing no periodic time dependence for the internal temperature ϑ_{B11} (lower, approximately linear curve).

The main distinction in the two experiments with different sequences of building panels is the increase in the internal temperature ϑ_{B11} during the entire measurement:

The Rohacell plate being the outer one results in a rise of the internal temperature from 29 ° C up to 30 ° C, i.e. by about 1 ° C (Fig. 2).

The polystyrene plate being the outer one results in a rise of the internal temperature from 27 ° C up to 30 ° C, i.e. by about 3 ° C (Fig. 3).

Another advantage of the external insulation with insulating material (in this experiment Rohacell) is the lower thermal stress for the static system (here polystyrene).

Further a phase shift for the temperature wave at different measuring positions can clearly be observed (the maximum delay in the occurrence of waves on the outside temperature and between panels).

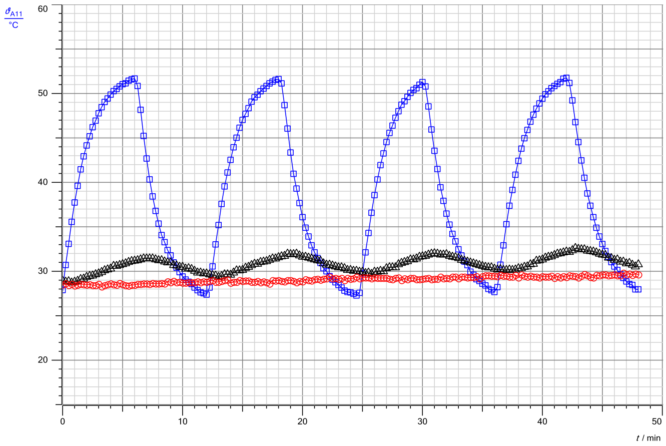

Figure 2: Attenuation of the temperature wave as it passes through an outer Rohacell (insulating) and a polystyrene plate

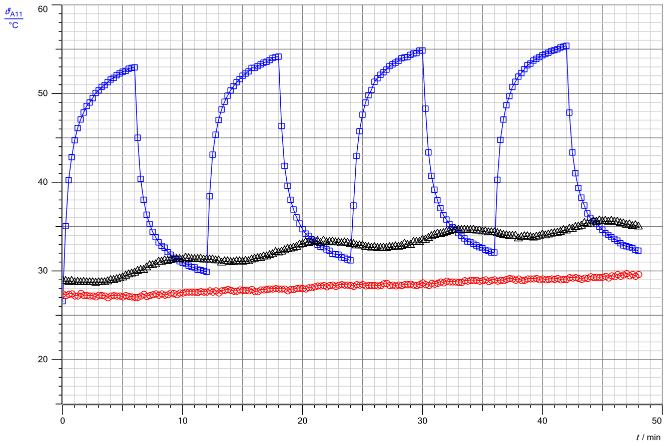

Figure 3: Attenuation of the temperature wave as it passes through an outerl polystyrene and a Rohacell (insulating) plate