Designing a Low-Energy Home

ACTIVITY 2_1: Observing ice melting in plates of different materials

Introduction:

Whenever we touch objects made of different materials we receive feelings of warmth or coldness. Consider the different feelings we have by walking barefoot upon a woollen carpet or upon a marble floor. In the same way, when we touch a metal object we have a feeling of cold quite different from the feeling that we have by touching a piece of wood. Can you explain why this happens?

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How could you perform a classroom experiment in order to prove what you answered to the previous question? Describe this experiment:

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The problem:

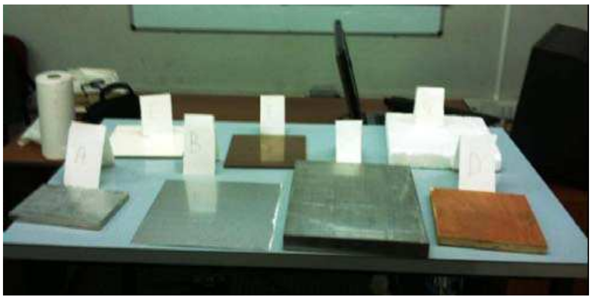
If we want that the ice cream or deep-frozen food we have bought do not melt during the time took to cover the distance between the store and home, we have to use special containers assuring thermal insulation. Which material makes the container a better insulator? Is it better to use metal, glass or plastic? By a simple experiment we shall try to give an answer to these questions.

Materials:

- 6 different plates (3 of aluminium with different thickness and area, 1 of wood, 1 of plexiglas and 1 of styrofoam)
- 1 surface temperature sensor
- Many ice cubes approximately identical

Suggestions for the experiment:

On the desk you can see six different plates. Each plate is identified by a letter (from A to F). The first three plates (A, B and C) are made of aluminium and differ in area and thickness. The D is a wooden plate, the E is plexiglas, while the last one (F) is styrofoam.



Touch the plates and describe the thermal feelings you are receiving.

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Now your teacher will pick up from the fridge six ice cubes approximately identical and will put down each cube upon a different plate. Before observing what happens, try to predict the melting order of ice cubes, starting from the quickest one. Insert into the following table the order number (from 1 to 6) for each plate. Try to explain your choice (if you want, you can ask your teacher to help you in measuring the plate temperature by means of the temperature probe).

A	B	C	D	E	F

Now observe the ice cubes melting. Describe what you have observed and make a comparison with your predictions.

DISCUSSION

Why the ice cubes melt when they are put down upon the plates?

Which properties of the plates do you think may affect the melting rate of ice cubes?

Do you think that the melting rate may depend on the initial temperature of the plates?

Which plate is, in your opinion, the best insulator and which is the best conductor?

Is the heat absorbed by each ice cube the same for all the cubes?

In depth analysis

The transfer of heat through solid material is known as **thermal conduction**. The rate of heat transfer by conduction through a layer with area *A* and thickness *d* when the temperature difference between external faces is ΔT is described by the Fourier law, which is mathematically written as:

$$\frac{\Delta Q}{\Delta t} = \frac{k}{d} A \Delta T$$

where ΔQ/Δt is the rate of heat transfer and *k* is the ***thermal conductivity***. This is a typical parameter of the material of the layer. The unit is watt/m °C. Thermal insulators, like air, show low values of conductivity (order of 10^{-2} W/m°C), while good conductors, like metals, have high values of conductivity (order of 10^{2} W/m°C).

Thermal conductivity is a property very different from heat capacity. Heat capacity represents the required amount of heat to produce a 1°C change in the temperature of an object. On the other hand, conductivity is the amount of heat flowing in the unit time through a layer with unit area and thickness when between the layer faces there is a difference of temperature of 1°C. In other words, we could say that the heat capacity of an object is associated to the capacity of the object to be warmed up or cooled down, while the conductivity represents the capacity to conduct heat. Insulators, for example, have low values of conductivity and also low values of heat capacity. For this reason, they warm up and cool down very quickly, but the heat flows across them very slowly. Also metals change their temperature rapidly because of low heat capacity, but the heat flow is much more higher than in insulators. Other materials, like water, have an high heat capacity and then they are used as cooling liquids (consider for example a liquid-cooled stroke engine).

By taking into account these try to explain data related to the ice melting time for the three aluminium plates. Do you think that these data may be interpreted only in terms of Fourier Law? Can you consider relevant the heat capacity of the plates? Make your comments below.

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ACTIVITY 2_2: Measuring insulation properties of different materials

The problem:

Thermal insulation of a house is a crucial problem when we want to minimize energy losses. But, which material it is better to use to build the walls or the roof of our house? Which material properties are the most suitable? The argument we are going to study will allow us to find some answers to these questions. We start by analysing with the aid of simple experiments the different behaviour of solid materials with respect to the transfer of heat by conduction.

Material for each group:

- 2 surface temperature sensors
- Styrofoam cup
- 5 squares of thickness 1 cm of different materials (aluminium, plexiglas, wood, plasterboard and styrofoam)
- 3 aluminium squares of different thicknesses (0,1 cm, 1 cm and 3 cm)
- Masking tape

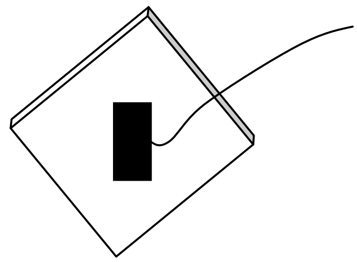
Suggestions for the experiment:

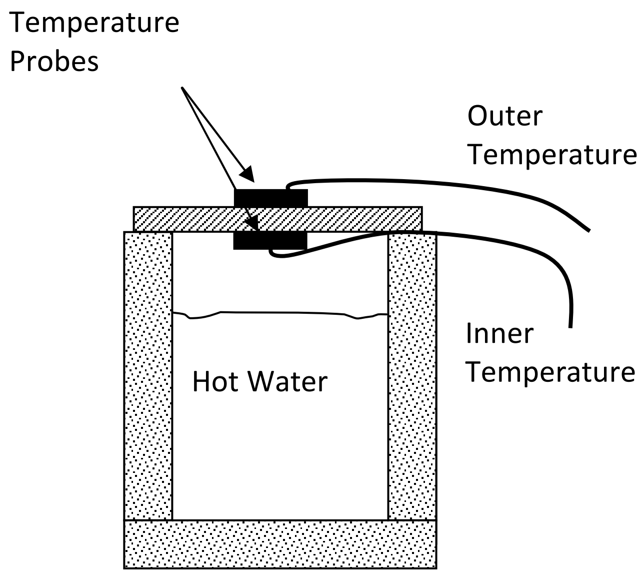
This experiment consists in measuring the difference of temperature across a square plate when there is a net heat flow. We shall use the setting shown in figure. We shall place the plate upon the cup filled with hot water and by means of temperature probes we shall measure the temperature of inner and outer faces versus time.

Pick a square of thickness 1 cm and tape a temperature sensor to each side of a piece of material. Fill the foam cup with very hot water until reaching ¾ of the height. By using a thermometer, measure the room temperature (T_{room}) and the temperature of the water (T_{water}). Write down the measurements

T_{room} = T_{water} =

Place the square on top of the cup, as shown in figure, and hold it firmly in place. Connect the two probes to the computer. Start to collect data.





Observe the graph of temperature vs. time and wait until the two curves (the inner and outer temperatures) reach a stable value. Read these values and report them in the table below.

Repeat the previous procedure with the other squares of different materials with thickness 1 cm. At the end, complete the table with the required data.

Material	Inner Temperature	Outer Temperature	Temperature Difference (ΔT)
Wood			
Plexiglas			
Styrofoam			
Plasterboard			
Aluminium			

DISCUSSION

Why is there a difference of temperature between the faces of the squares?

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List the materials in order from highest to lowest temperature difference.

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Which material do you think is the best conductor? And the best insulator?

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Try to explain why, although water temperature and room temperature do not change, the inner temperature of the squares is different depending on the material.

Now, we shall analyse how the thickness of the squares affects the heat conduction. To do this, repeat the previous measurements by using, this time, the three aluminium squares of thicknesses 0,1, 1 and 3 cm. Report data in the following table.

Material	Inner Temperature	Outer Temperature	Temperature Difference (ΔT)
Aluminium 0,1 cm			
Aluminium 1 cm			
Aluminium 3 cm			

DISCUSSION

How does the difference of temperature change when thickness increases?

In order to make thermal insulation of a house more effective do you think is it better to use thicker walls or not? Explain.

In depth analysis:

The rate of heat transfer by conduction through a layer with area *A* and thickness *d* when the temperature difference between external faces is ΔT is described by the Fourier law, which is mathematically written as:

$$\frac{\Delta Q}{\Delta t} = \frac{k}{d} A \Delta T = K A \Delta T$$

where ΔQ/Δt is the rate of heat transfer and *k* is the ***thermal conductivity*** of the material.

The parameter *K = k/d* is measured in Kcal/m^2 °C and represents the heat amount transferred trough a layer with unit area (1 m^2) per hour and per unit difference of temperature.

In the table below, we have reported the parameter *K* for some materials commonly used in home-building.

External wall	26 cm air brick	1,2
Internal partition wall	12 cm air brick	1,5
Floor	Concrete and squares	1,0
Window	4 mm glass	4,3
Door	Wood	3,6

Based on the data in the table, try to estimate the heat loss by conduction across the walls, the floor, the windows and the doors of your classroom during an half-day (5 hours) lesson session in a winter day (assume a room temperature of 20 °C and an outer temperature of 5° C) . Which elements of your classroom lose the most heat by conduction?

Conclusions:
For each activity summarize what you have learned at the end of the activity and explain how you have drawn your conclusions.