Activity: Insulate All the Things!
Grade Level: 6-8 Group Size: 3-6
Time Required: 60min + Break (1-2hrs)

Subject Area: Science and Technology
- Energy & Energy Conservation
- Also relevant to:
  - Architecture
  - Civil Engineering

Summary:
This activity is designed to teach middle school students the basic concepts of heat transfer and insulation, and how energy conservation relates to these concepts. It is intended as a demonstration to get students thinking about how they can conserve energy through better insulation, and what makes better insulation.

Science and Technology Connection:
When designing new homes, architects must use many different insulation materials. They are constrained by the environment the home will be in (how hot, cold, rainy, sunny, etc.), the new homeowner's needs, cost, and the different materials available. They must balance all of these factors to create the most energy-efficient home they can. Architects use a materials R-value to determine how good the insulation is when making these choices.

Contents:
1. Learning Objectives
2. Materials & Equipment
3. Instructor Preparation
4. Introduction/Motivation
5. Procedure
6. Discussion
7. Assessment
8. Definitions and Concepts
9. Approximate Timeline
10. Extensions
11. Activity Scaling
12. Attachments: Worksheet & Images
1. Learning Objectives:

After this activity, students should understand:
1. How heat flows/moves
2. What makes a good insulator. Basic conceptual understanding of R-values
3. Insulation saves energy

2. Materials and Equipment:

Equipment:
- Mass balances – one per group
- Strainer – one per group
- Timer (e.g. clock, watch, phone, stopwatch) – one per group
- Large cooler or sink with stopper
- Large beakers or other similar sized containers (Note: empty cans with sharp edges sealed with strong tape such as double-layered duct tape work well)
- Large-tipped marker (optional)
- Thermometer (optional)

Materials:
- Cardboard boxes, one per group (6”x6”x6”)
- Rigid insulation board
- Insulation materials
  - Wool/felt/fleece
  - Rigid insulation board
  - Cotton batt
  - Cardboard
- 1-gallon size sealable plastic bags (e.g. Ziploc, Hefty)
- Painter’s tape or another loose-adhesive tape, meant for easy removal
- Ice
- Worksheet, one per person
- Glue (optional)

Please Note: Any materials can be used as demonstration insulation materials. Different materials and thicknesses from those listed can be used. Be sure to adjust R-values listed in this activity for those of any materials you choose to substituted.

3. Instructor Preparation:

- Cut 6x6 inch section of rigid insulation, one per box. Glue or tape to the bottom of each box – this will serve as a rigid base of insulation that is equivalent for all boxes.
- Cut insulation materials into panels
  - 4 panels: (6 inch + material thickness x 6 inch + material thickness)
    - e.g. ¼in polyester batt: 6¼ inch x 6¼ inch)
  - 1 panel: (6 inch + 2xmaterial thickness x 6 inch + 2xmaterial thickness)
    - e.g. ¼in polyester batt: 6½ inch x 6½ inch)
  - Optional: label 4 side panels with a large S, top panel with a large T
• **5-10min before the activity is to take place:** Make a giant cooler filled with ice water. The water temperature must be at the same temperature (32°F, 0°C) before beginning the experiment for all boxes or the experiment will not work
  - A cooler with a spigot is easiest for this purpose as it is easy to get water from the cooler, so it can be packed with ice to minimize the time needed to bring the water to temperature
  - If using a large sink with a stopper, fill the sink with ice and then fill with water
  - Verify that the temperature reaches 32°F using thermometer. If no thermometer is available, keep adding ice until it no longer is visually melting in the water

4. **Introduction/Motivation:**

When you place your hand in cold water, your hand feels cold. If you leave it there long enough, your hand will stop feeling cold. If you place your hand in hot water, your hand feels hot, but if you leave it there, your hand will stop feeling hot. Why is this? No, your hand is not ‘going numb’ or ‘becoming desensitized’ – your hand is experiencing heat flow. Heat is flowing between the water and your hand until both are at the same temperature.

Can anyone think of other examples of heat flow? (Possible examples: opening a refrigerator and ‘letting the cold out,’ jumping into a cold pool, ice cube melting in the hot sun). Does anyone know how heat flows? (Answer: heat flows from high temperature to low temperature – hot to cold). Correct the common misconception that you can "let the cold out" of an open refrigerator – heat is flowing in, not cold flowing out.

Today we are going to be architects of small cardboard houses. In this activity we are going to try to prevent heat flow. This is similar to what architects have to do to prevent your house from getting too cold in winter, and too hot in summer. Our goal is to prevent the heat of the room from melting ice. We’ll be doing this by creating a barrier between the ice and the room. We call this barrier insulation. We will test different kinds of insulation by wrapping cardboard boxes with panels of insulation and placing ice water in the cardboard boxes. We’ll then measure how much ice melts in 15 minutes for the different kinds of insulation. We’ll also have a control: an uninsulated container with ice water, to see how much ice melts when there is no insulation at all.

5. **Procedure:**

1. Split class into groups of 3-6. Have each group pick one insulation material, or assign insulation materials
2. Hand out materials & instruction worksheets. Have students rank their guess for what they think will be the best insulation materials on their worksheets.
3. Assemble insulation materials around the boxes by taping panels to the outside of the box sides using painter’s tape (or other loose-adhesive tape). Have students follow diagrams attached to their worksheets to step 4. Do not close the box or put the top panel of insulation on the box yet.
For the following steps, caution students to touch the ice as infrequently as possible. Body heat will melt the ice and skew results!

4. Weigh beaker, put ice in beaker and weigh ice+beaker together. Target ~900g. Goal is to ensure everyone has roughly equal amounts of ice. Put the plastic bag in the box and fill with the measured ice.

5. Weigh the water. Fill the ice-filled bag with water.

6. Close box and attach top insulation panel.

7. **Discussion**
   
   **BREAK: 1-2 hours**
   
   Go to lunch, do other classwork, etc. This break is needed so there are measureable differences between the different insulation materials. Be careful to not exceed 2 hours or ice will fully melt (assuming a room temperature of ~70°F) and results will not be able to be compared.

8. Strain the water into a beaker and weigh the total water that was in the bag.

9. Subtract beaker from all mass measurements to get mass.

10. Subtract initial water mass from total water mass after the experiment.

11. **Assessment:** Compare the results, discussion of results

12. **Cleanup**

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6. **Discussion:**

Now that we've built our insulated houses, can anyone describe what insulation looks like in a typical house? (Students may have seen homes being built – exteriors show examples of rigid board insulation, or seen uncovered insulation in an unfinished attic or basement – examples of fiberglass insulation). Which of our kinds of insulation look like what you see in a house?

How do architects know what the best insulation material is for a particular application? No, they do not memorize every material available to them – they instead use a table of material R-Values. R-values are specific to each material, and tell the architect how *thermally resistive* that material is – in other words, how hard it is for heat to flow through that material. Larger R-values have a greater resistance to heat flow than lower R-values (they are better insulators).

\[ R = \frac{L}{k} \]

where L is the material thickness and k is the material thermal conductivity.

R-values can be expressed as a total for a particular insulation installation; for instance, a 3 ½ inch layer of fiberglass batt (which fits into a typical wall in your home) has a total R-value of 11.0. R-values can also be expressed as per a standard thickness of the insulation material, such as per inch. For example, if a 3 ½" layer of fiberglass insulation has a total R-value of 11, then it can also be described as having an R-value per inch of 3.14 (11.0 total R-value divided by 3 ½ inches of insulation = 3.14 per inch of insulation).

*http://www.insulation.org/articles/article.cfm?id=IO090302*
Example R Values:

<table>
<thead>
<tr>
<th>Material</th>
<th>Total R values [hr×ft²×°F/Btu]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3½ inch fiberglass batt</td>
<td>11.00</td>
</tr>
<tr>
<td>4 inch common brick</td>
<td>0.80</td>
</tr>
<tr>
<td>2x4 softwood lumber</td>
<td>4.38</td>
</tr>
<tr>
<td>Gypsum board (drywall)</td>
<td>0.45</td>
</tr>
<tr>
<td>Single pane glass window</td>
<td>0.91</td>
</tr>
<tr>
<td>3/4&quot; polyurethane foam insulation board</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Of the above listed materials, 3½ inch fiberglass batt has the highest total R-value, and is therefore the best insulation material. Which of the listed materials are the best per inch of material? (Answer: ¾” polyurethane foam) Which of our materials do you think will have the highest R-Value?

Architects use insulation to prevent heat flow, but no matter what heat will flow in and out of a house. Insulation slows down the heat flow. Now let’s think about our own homes – why do they not get too cold or too hot? We use air conditioning and heating to keep our homes at a comfortable temperature. These work by turning on when the temperature in your home goes above or below the set temperature by more than a few degrees.

If our homes had no insulation, how often do you think your air conditioner would have to run in the summer? Do you think it would be able to turn off every once in a while? (Answer: The air conditioner would have to run all the time – heat would flow into the house too fast to give it a break.) Running your air conditioner or your heater requires energy. Some of you may have your parents (or guardians) that like to change the set temperature to save energy – in the summer they may set the temperature inside the house to 80°F, in the winter they may set it to 60°F. This means that the air conditioner or heater will have to be on less often, which saves energy. Has anyone heard the term energy efficiency? Energy efficiency is "using less energy to provide the same service."* A home with better insulation materials is a more energy efficient home!

*http://eetd.lbl.gov/ee/ee-1.html
7. Assessment:

Which insulation materials performed the best – which materials had the least amount of ice melt? In the bottom of your worksheet, rank the materials by how well they performed.

Here are the approximate real-world R-values for our insulation materials:

<table>
<thead>
<tr>
<th>Material</th>
<th>R-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid insulation board (¾”)</td>
<td>4.0 (<a href="http://building.dow.com/en-us/products/s/styrofoam-brand-residential-sheathing-us-only">http://building.dow.com/en-us/products/s/styrofoam-brand-residential-sheathing-us-only</a>)</td>
</tr>
<tr>
<td>Polyester Batt (½”)</td>
<td>2.0 (Estimate; using same as cotton but 2x thickness)</td>
</tr>
<tr>
<td>Cotton Batt (¼”)</td>
<td>1.0 (<a href="http://www.cottonbatts.com/compare.php">http://www.cottonbatts.com/compare.php</a>)</td>
</tr>
<tr>
<td>Cardboard (3/16”)</td>
<td>0.4 (estimate, from AHSRAE Fundamental 2009, using values for “Homogeneous board from repulped paper”)</td>
</tr>
<tr>
<td>Bubble Wrap, ¼”</td>
<td>Unknown; no data found. Estimated as 1.0</td>
</tr>
</tbody>
</table>

8. Definitions and Concepts:

Insulation: to cover, line, or separate with a material that prevents or reduces the passage, transfer, or leakage of heat
Control: a constant and unchanging standard of comparison in scientific experimentation
Barrier: an obstacle that prevents movement, flow, or transfer
Material Property: an attribute, quality, or characteristic of something
Thermal Resistance: How difficult it is for heat to flow through a material
Batt: a piece of felted material used for lining or insulating. (Felted material: hairy or otherwise filamentous material that is densely packed or tangled)
Energy Efficiency: using less energy to provide the same service
R-Value: Measure of thermal resistance

9. Approximate Timeline:

- Intro, assigning materials: 10min
- Gather materials: 2min
- Build: 10-15min
- Discussion: 15-20min
- Break: 1-2hrs
- Assessment: 5min
- Cleanup: 2min

10. Extensions:

- Windows
  - See how introducing a window effects the insulation of a home. Chose your best performing insulation material (or the one with the highest R-value)
  - Have students cut a square out of a cardboard box and cover it with a piece of acrylic (or other stiff clear plastic). Have them create a 6x6x6inch box out of just acrylic. Perform the experiment testing a fully
insulated box, a box with a window, and the ‘all window’ box. Compare results.
  o Windows are bad insulators! How do we make them better? Include single vs. double vs. triple pane windows in discussion.

- Conduction, Convection, and Radiation
  o If students have already studied these concepts, include them in the discussion – how are the best performing insulators preventing heat flow through these mechanisms?
  o Look at the equation for an R-value – it only takes into account conductivity! How do we choose the best materials when convection and radiation are our largest sources of heat?
  o Convection: Why do insulators that trap air work well? Test different materials that trap different volumes of air (small, closed pores, open network pores, uninterrupted film of air) – air is a good insulator when it cannot move, i.e. when it cannot participate in convection!
  o What about other methods of preventing heat from entering a living space? Test conductive and reflective materials against a heat lamp or other radiative source of heat.

- Historical Materials
  o Test different historical materials used for home insulation – furs, leather, feathers & down, straw, mud, stone, brick, etc.
  o Include discussion of the history surrounding these materials & why they were used in different

11. Activity Scaling:

Scaling Down:

- Limited time:
  o A heat lamp, low-heat oven, or alternate heat source can be used to increase the temperature gradient and speed ice melting in this activity

- Limited Resources:
  o Not all materials need to be demonstrated. Split the class into groups that will test a box with insulation, and groups that will test uninsulated boxes. Have students study differences in their measurements and discuss how error can be introduced to this experiment. What is the error? Is it significant? Discuss the idea of “significant” values in science and engineering.

    o Perform the experiment as a demonstration instead of a class activity. Only one insulation material needs to be used. Set up demo with one cardboard box w/ insulation of choice and one bag of ice water. Show the differences in the cardboard box as insulation versus no insulation at all. Limit the break time – keep an eye on the bag of ice water to ensure ice does not fully melt.
Scaling Up:

- Repeat experiment changing material thicknesses – how does material thickness effect the insulation properties?

- Test more materials!
  - Note: Use of real insulation materials other than rigid insulation board is not recommended due to required personal protective equipment and safety and health hazards associated with improper handling of these materials.
Insulate All the Things! Worksheet

Which do you think will be the best insulation materials? Rank what you think below:

Best: 1. _____________  Possible Materials:  Rigid Insulation Board  
       2. _____________  Polyester Batt  
       3. _____________  Cotton Batt  
       4. _____________  Bubble Wrap  
Worst: 5. _____________  No insulation

Instructions:

1. Collect materials  
   a. Matching insulation panels (5)  
   b. Box (1)  
   c. Large Beaker (1)  
   d. 1 Gallon Sealable Bag (1)  
   e. Roll of Tape (1)  
2. Tape panels to sides of box, following diagrams (below)  
3. Weigh your beaker  
   Beaker mass: _________ g  
4. Add about 900g of ice to the beaker. Weigh ice + beaker  
   Beaker + ice mass: _________ g  
5. Put the plastic bag in the box and fill the box with the measured ice
6. Weigh the water in the beaker (make sure to use the ice-cold water!)

   Beaker + water mass:
   _________ g + _________ g + _________ g

   - _________ g = _________ g
     (total water mass + total beaker mass)

7. Add measured water to the bag with ice. Make sure to nearly fill the bag — you want to leave some room to seal the bag!

   !! You may need more than one beaker of water to fill the bag.
   Write down the mass of each beaker full of water you use. If the bag is full but you have measured water leftover, weigh the beaker with unused water and subtract it from the total. Remember to subtract ALL beaker masses from later measurements !!

8. Close box and tape insulation panel to the top of the box.

9. Discussion

10. Using strainer, strain the water into a beaker and weigh the total water that was in the bag.

    Beaker + water mass: _________ g + _________ g

    = _________ g
    (total water mass + total beaker mass)

11. Subtract beaker from all mass measurements to get mass.

    Initial water mass – total beaker mass = _________ g

    Final water mass – total beaker mass = _________ g

12. Subtract initial water mass from total water mass after the experiment.

    Initial water mass – final water mass = _________ g

13. Assessment: Compare the results, discussion of results

14. Cleanup
Real-World Insulation