$$Q = \frac{A \times \Delta T}{R}$$

How this equation helps us design energy efficient homes

Background

In the application (the app) the equation $Q = (A \times \Delta T)/R$ is used to show how the size of a house, the thermostat setting, and the amount of insulation affect the amount of energy needed to heat the building. The equation is defined here:

Q = heat flow. The ***power*** to keep the house warm.

A = the size of the house. The ***surface area*** of all the outside walls, roof, and floor.

ΔT = the ***temperature difference*** from inside to outside. ΔT is said "delta T". Engineers use the Greek letter Δ to mean "difference".

R = the average R value or ***insulating value*** of the building envelope.

More information about each of these factors:

Q = heat flow. This is the ***power*** to keep the house at the temperature set on the thermostat, measured in kiloWatts (kW). Energy (Power x Time), will keep the building at the temperature set on the thermostat. As A, ΔT, and R change, Q will change.

- As shown by the app, the higher the thermostat setting, or the colder it is outside, the more energy needed to heat the house.
- As well, the larger the house, the more energy needed, and
- The older (assume poorly insulated) the house, the more energy needed to keep it warm.

A = the size of the house. This is the ***surface area*** of all the outside walls, roof, and basement (walls and floor). The walls, roof, and floor are each considered separately, as they will be constructed differently. As shown by the app, the larger the house, or the larger the surface area of the house, the more energy will be needed to keep it warm. This app has 3 house sizes, shown in square meters. You can choose one of the provided house sizes, or something in between. Notice how the surface area changes as you change the size of the house. The surface area is "A".

ΔT = the ***temperature difference*** from inside to outside. **ΔT** is said "delta T". Engineers use the Greek letter Δ to mean "difference". The app allows you to set the thermostat (which controls the indoor temperature). It also allows you to set the outdoor temperature. Notice how **ΔT** changes as you change the indoor and outdoor temperatures.

ΔT: Temperature Difference – Do the Math

- If the thermostat indoors is set to +18°C and it is –20°C outdoors, that is a 38°C temperature difference, or **ΔT** of 38°C.
  - *The equation looks like:* 18–(–20) =18+20 =38 °C
- If the thermostat is set to +17°C and the outdoor temperature is +5°C, **ΔT** is 12°C.
  - *The equation looks like:* 17 – (5) = 12°C

R = the average R value or ***insulating value*** of the building envelope. The R value is a measurement of how well building materials insulate against heat loss or how well they resist the movement of heat. In our houses, insulation in the walls, and ceiling, and basement, helps our house resist the loss of heat in winter. The amount of insulation and its R value tell us how quickly heat can be lost. Typically, old houses had little or no insulation while newer houses, which are built to a standard code, are required to have more. Very energy efficient houses, like the passive house described on page 3, have a lot of insulation and a lot of effort has gone into making the houses resistant to heat loss. ***Note: All this insulation that keeps your house warm in the winter, also helps keep it cool in the summer. The heat of outdoors will move more slowly through well insulated walls to get into the house.***

Separating R and Q values: walls, basement and roof

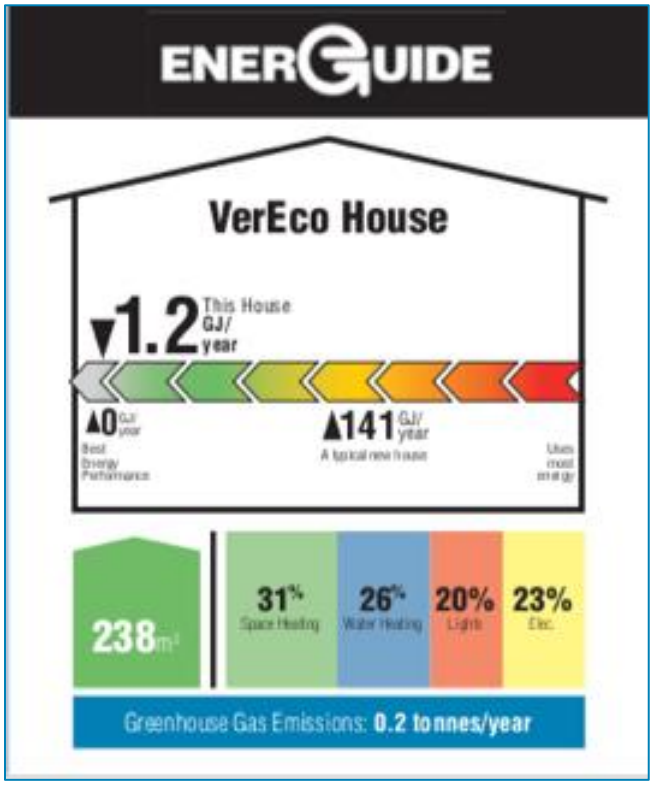
- Because the insulating value of walls, basement and roof are different from each other, R is separated into R_{walls}, $R_{basement}$, and R_{roof}.
- The energy used by each will also be different and so Q is separated into Q_{walls}, $Q_{basement}$ and Q_{roof}.
- Q_{total} represents the total energy used by all of walls, basement and roof.

Here is insulating value information, for a variety of materials.

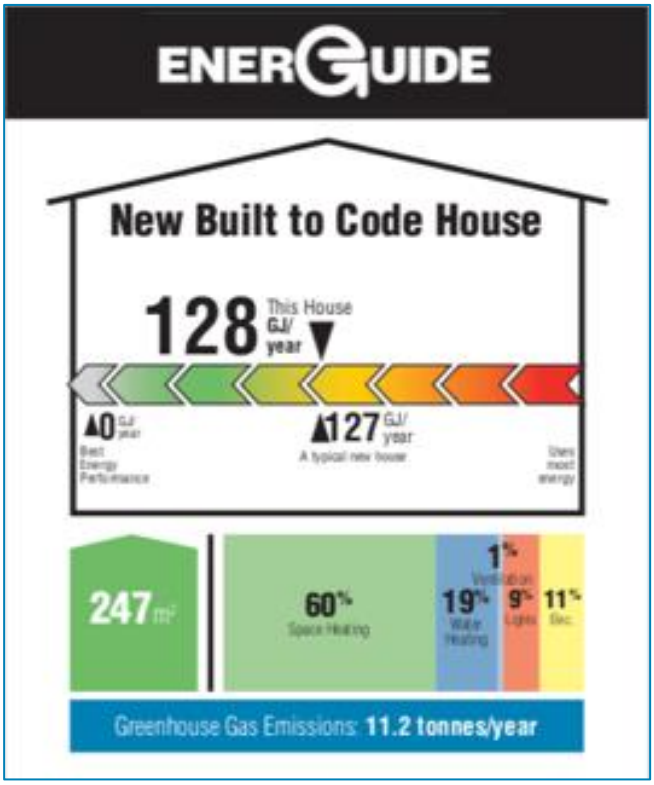
Building Materials	**R** (°F x ft² x hr/BTU)	**RSI** (m² x °C/W)
Fiberglass batt	3.14/inch	.022/mm
Cellulose blown (wall)	3.70/inch	.026/mm
Polyurethane (foamed in place)	6.25/inch	.043/mm
Extruded polystyrene (EPS) (rigid foam)	5.00/inch	.035/mm
Gutex® wood fibre	3.9/inch	.027/mm
Roxul board or batt	4.00/inch	.028/mm
Insulated concrete forms	4.00/inch of EPS (R21 for the whole wall thickness)	.028/mm (RSI 3.7 for the whole wall thickness)
Note: Building materials usually use imperial units (i.e. inches, feet and yards) This chart and the app use metric R-value, commonly referred to as RSI. To convert from imperial R to RSI divide R by 5.68. To convert RSI to imperial, multiply RSI by 5.68.		

EnerGuide® Building Ratings

EnerGuide® is an energy rating system for buildings that measures the amount of energy the home uses. The calculation is based on heating the building, heating water, and electricity use. Here are four EnerGuide® ratings for comparison (pages 3 and 4). *The app only calculates heating energy, and is much less detailed than EnerGuide®, so the app results won't match the EnerGuide® results.*



The Vereco house was built in 2010 but built to be very efficient with RSI 7.6 in the walls and RSI 14.1in the attic. At 238 m^2, it is above average in size. Designed to use 53GJ/year, it produces almost as much energy as it uses, from solar panels that provide electricity.



The New Built to Code house was built in 2019, with RSI 3.9 walls and RSI 8.8 in the attic. At 247 m^2, it is above average in size.

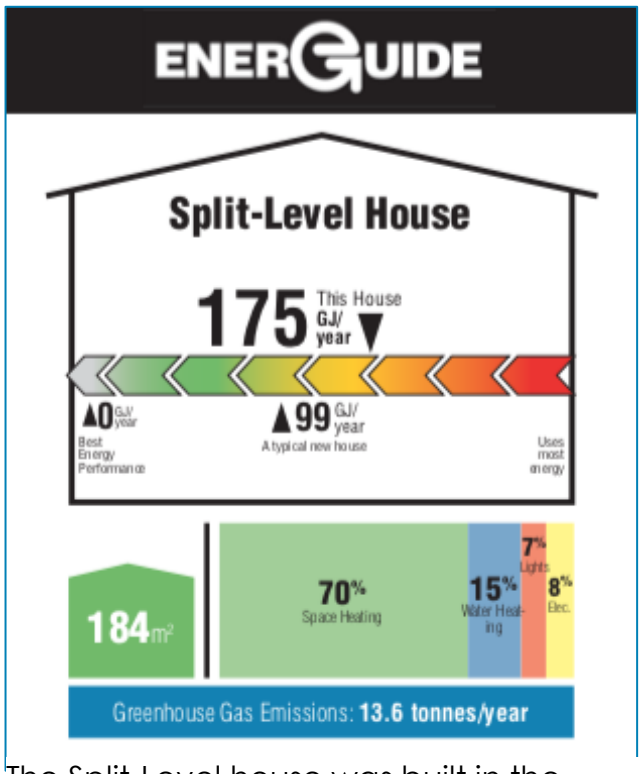
What is a Passive House?

Passive house buildings are designed and built to be super energy efficient, consuming up to 90% less heating and cooling energy than a conventional house. The remaining energy needed to heat or cool the home is very small and most don't even need a furnace. *Source: Passive House Canada*

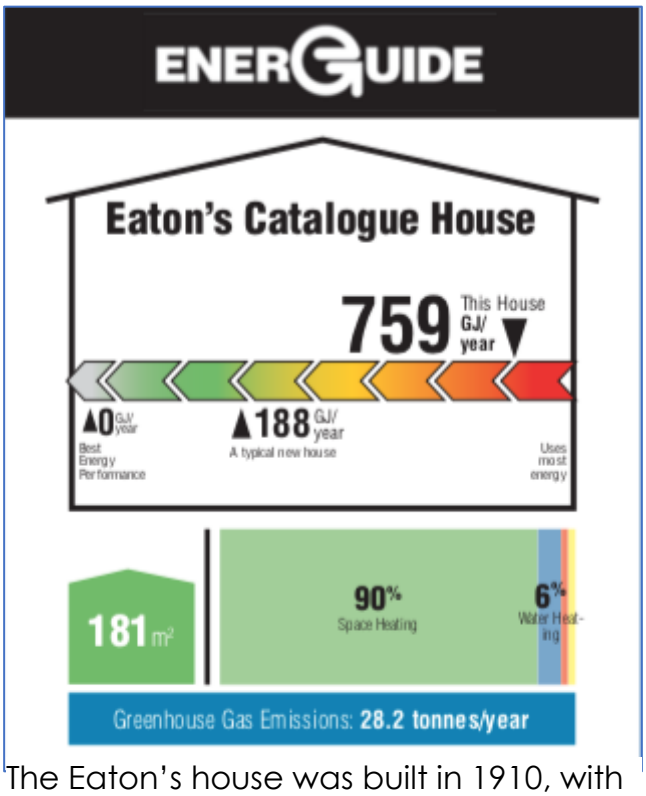
Here are values for one passive house built in Saskatoon in 2015

Size: the house is **90 m^2**

Effective R or insulating values: **RSI 11.6** walls **RSI 10.9** basement **RSI 19.2** roof



The Split-Level house was built in the 1970's, with RSI 2.1 in the walls and in the attic. At 184 m², it is just below average in size.



The Eaton's house was built in 1910, with no insulation in the walls or in the attic. The building materials provide RSI 0.7 for the walls and RSI 0.3 in the attic. At 181 m², it is below average in size.

Procedure

Use the app to do the following questions:

1. When you play with the Q= AxΔT/R app, what happens to the energy consumption of the house when you turn down the thermostat? Why?

2. What two things make ΔT change?

3. Calculate ΔT using these indoor and outdoor temperatures. Calculate ΔT by subtracting the outdoor temperature from the indoor temperature.
   a) Indoor 22°C, outdoor -23°C
   b) Indoor 17°C, outdoor -13°C
   c) Indoor 24°C, outdoor 15°C
   Apply these to the app. Which causes Q to be the highest?

4. Use the Reset button (bottom left) to return the app to the pre-set numbers. Write down the value of Q for the roof, walls, and the total.

   Now, double the RSI-value in the roof. What happens to Q_{roof}, and Q_{total}? Why? Now double the RSI-Value in the walls. Which has more impact? ***Think:*** Why do you think this is the case?

5. If you add insulation to the roof, but not to the walls, does it still lower the home's energy consumption?

6. Why does a bigger house use more energy?

7. Use the Reset button to return the app to the pre-set numbers. Use the app to calculate the effective RSI, Q, and Annual energy for heating for the four preset houses in the app. Create a bar graph comparing all these variables. What do you notice?

8. Use the Reset button to return the app to the pre-set numbers. Take the information for the Saskatoon passive house (page 3) and apply it to the app. Use the size of the house (90 m^2) and move the RSI buttons as close as possible to the passive house RSI values provided.
   What is Q_{total} and the annual energy?

9. Looking at the Double Wall Construction information, and thinking about Q = A ΔT/R, how does double wall construction reduce the energy consumption of a house? ***Think:*** Why does thermal bridging lower the effective RSI value of a wall? How does reducing thermal bridging reduce the energy consumption of the house?

Effective R-Value: An Explanation

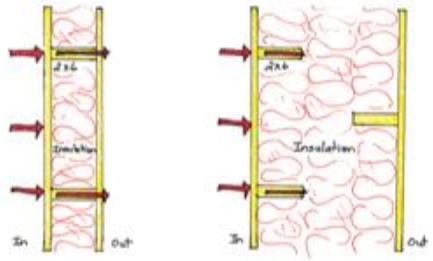
When we build a wall, parts of the wall are mostly wood, and parts are mostly insulation. So, we talk about an **effective R-value**. This takes into account the different materials and gives the overall R-value of the wall.

Double Wall Construction

Thermal Bridging: Heat conducts through wooden studs more easily than through insulation.

Standard Wall: The studs create a thermal bridge through the wall, allowing heat to escape.

Double Wall: Offset studs allow for an uninterrupted layer of insulation.



Thermal Bridging: Standard Wall Construction

No Thermal Bridging: Double Wall Construction

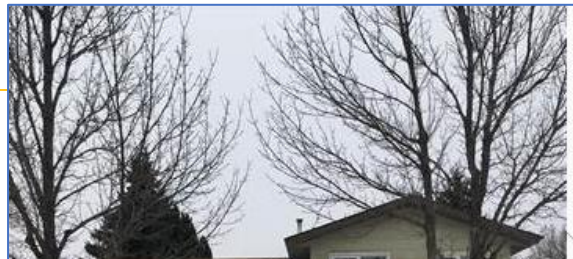
10. Use the Reset button to return the app to the pre-set numbers. Use the app to find Qtotal for each of the 3 real estate listings below or look up others on your own.
    - For each listing, use the comparative size and age of the houses, with a constant thermostat setting to find Q. ***Note: Older homes in general, have less insulation and older, draftier windows. Set the RSI based on the age the home was built.***
    - Now apply the size of the 1970's split level home but choose the preset RSI values for the *Home Built to Code*. What is the difference in energy use (Q?) What does this information tell you?

1955 ft^2/181.6 m^2

4 Beds | 2 Baths | 1,955 Sqft | 0.129 ac Lot Size

Residential

Year Built **2019** (Home built to code)



1060 ft^2/98.5 m^2

4 Beds | 2 Baths | 1,060 Sqft | 0.144 ac Lot Size

Residential

Year Built **1978** (1970's Split Level)

1705 ft^2/158.4 m^2

6 Beds **3** Baths **1,705** Sqft **0.108 ac** Lot Size

Residential

Year Built **1910** (Similar age to Eaton's house)

11. Use the Reset button to return the app to pre-set numbers. Use the app and the Building Materials R Values chart (page 2) to compare the heat flow (Q) of the following three ways to build a house. Keep the surface area (A) and thermostat setting (ΔT) constant for all three. Note: Use RSI and multiply by the number of millimeters, after converting inches to millimeters.
    a) You build a house and insulate it with 5 ½" of fiberglass batt.
    b) You add 2" of Extruded Polystyrene to the exterior of the wall from "a".
    c) You build a double wall with 10 ½" of cellulose blown insulation.

Curriculum Connections

Grade 7 Science: Outcome: HT7.1 Assess the impact of past and current heating and cooling technologies related to food, clothing, and shelter on self, society, and the environment. **HT7.3** Investigate principles and applications of heat transfer via the processes of conduction, convection, and radiation. **Mathematics: Outcome: N7.2** Expand and demonstrate understanding of the addition, subtraction, multiplication, and division of decimals to greater numbers of decimal places, and the order of operations. **P7.2** Demonstrate an understanding of equations and expressions by: distinguishing between equations and expressions, evaluating expressions, verifying solutions to equations. **P7.3** Demonstrate an understanding of one-and two-step linear equations of the form ax/b+c=d.
W&A Math 10 WA10.3 Demonstrate using concrete, and pictorial models, and symbolic representations, understanding of measurement systems including: The Système International (SI), The British Imperial system, The US customary system. **WA10.4** Demonstrate, using concrete and pictorial models, and symbolic representations, understanding of linear measurement, including units in the SI and Imperial systems of measurement.
Physical Science 20: PS20-HT1 Analyze, qualitatively and quantitatively, the effect of heat on matter during temperature changes and changes of state using kinetic molecular theory.
Construction and Carpentry 10, 20, 30 Demonstrate an understanding of working drawings, floor plans, wall sections, skills and knowledge of framing, sheathing walls, pilings, footings, basement wall construction, etc..