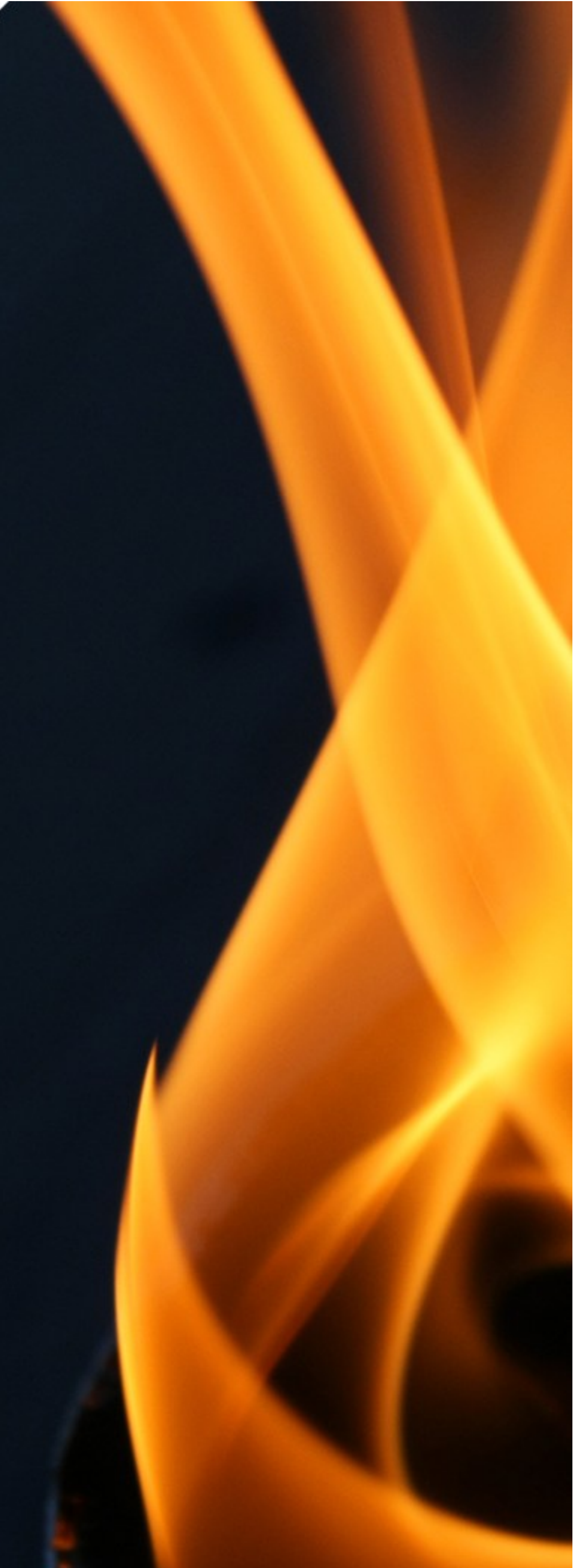

the gaia project
realistic environmentalism

# Project Guide: Energy Audit: Heating

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**Energy Audit: Heating**

A guide to isolating and evaluating heating energy use in you energy audit and reduction project



*The Gaia Project* is a charitable organization dedicated to providing project based learning opportunities in the areas of energy, environment and sustainable engineering.

We develop projects, provide professional development, technical support and ongoing project support for teachers and students. Our projects aim to incorporate three key principles, which symbolise our focus on realistic environmentalism.

1. **Data Informed Decisions** – We want students to be able to explain why, and quantify the effect of each decision they made along the way to their final solution.
2. **Economic Assessments** – We expect students to be able to assess the cost effectiveness of their solutions, and be able to optimize their projects with limited budgets.
3. **Environmental Impact and Lifecycle Assessments** – We need students to take a holistic view to their projects. This means looking at their projects from cradle to grave, as opposed to just examining the use phase, and acknowledging that greenhouse gas reduction is not the only environmental issue at stake.

For more information, please visit www.thegaiaproject.ca

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# Heating

In Canada, heating is usually the primary source of energy use in our residential and commercial buildings. In other parts of the world, it may be the reverse, where air conditioning is the primary source.

It is also one of the more difficult ones to track, as the equipment is generally too large or too complex to measure with the equipment we have available. It is also incredibly dependent on one element outside of our control—outdoor temperature.

That said, small changes to the way we heat buildings, or retain that heat can have huge cost implications due to the sheer amount of energy we consume on heating.

## Discussing with your class

Ask students how their home is heated. How long does it take a room to warm up once the thermostat has been turned up (will depend on the type of heating system)? What do you know about the insulation of your house? How is heating your home different from heating the school? How well do you think the school is insulated?

## Essential Resources

### Energy Audit: The Gaia Project

http://www.thegaiaproject.ca/projects/sustainability-planning/energy

### Sustainability Plan: The Gaia Project

http://www.thegaiaproject.ca/projects/sustainability-planning

# Using Energy Bills

Previous energy bills can be a good place to start, as they provide details on quantities of energy delivered, the cost and the period it covers. However, they are limited in that they do not break down exactly where the energy was used and what the usage profile was.

This guide is going to examine three main fuels (oil, natural gas and electricity), but the principles discussed apply everywhere. Some methods are easier than other, but unfortunately, you probably won't be able to choose which method you can use.

## Oil

Oil heating systems have the benefit of normally being separated from lighting, plug-in loads, ventilation and air conditioning loads. This means that they usually are a pretty good indication of how much energy was used for heating. Unfortunately there are a couple of problems we need to deal with first.

The first major problem we have is that the quantity of oil delivered is not necessarily the same as the quantity of oil used since the last delivery. This would only be true if the oil tank was filled to capacity (or to the same fill point) each delivery. Since there is a tank of oil on site to act as a buffer, it is possible to add 1,000L a month but use 2,000L a month for some time before the tank reaches empty.

We have two potential options to solve this problem.

- Discuss with your administration and school district about the benefits of tracking energy use. This would be made easier by ensuring that the tank was filled to capacity every time it is filled. This ensures that the amount of oil put into the tank is equal to the amount of oil used in the previous period, as in Table 1.

**Table 1:** Oil used per period where the tank is filled to the same point

| Date | Oil Into Tank (Litres) | Oil Used Since Last Fill (Litres) |
|---|---|---|
| Jan-15 | 2000 | 2000 |
| Feb-15 | 2200 | 2200 |
| Mar-15 | 1800 | 1800 |
| Apr-15 | 1400 | 1400 |
| May-15 | 1000 | 1000 |
| Jun-15 | 500 | 500 |
| Jul-15 | 100 | 100 |
| Aug-15 | 100 | 100 |
| Sep-15 | 200 | 200 |
| Oct-15 | 400 | 400 |
| Nov-15 | 800 | 800 |
| Dec-15 | 1400 | 1400 |

- Check your oil tank to see if there is a level indicator on it. You may be able to estimate how full the tank is simply by tapping on the side of it, listening for a change in the sound, and measuring the tank. If you can tell how full it is, you need to make sure someone is present every time the tank is filled to record how much oil was added to the tank and on what date. See Table 2.

Once we know how much oil is burned per period, we are now faced with our second problem. We know how much oil was used in a given period, but not how it was used during that period. It is highly unlikely that the same amount of oil was used every day.

Fortunately, there is a solution for that too. We can use the concept of **degree days** (discussed in detail in our Energy Audit: Degree Days package) to actually estimate the amount of oil burned on any given day based on the outdoor temperature.

Let's say we know that in a one week period in January, we know that 1,000L of oil has been burned.

**Table 2:** Oil used per period where the tank is not filled to the same point each time

| Date | Oil Before Fill (L) | Oil After Fill (L) | Oil Used Since Last Fill (L) |
|---|---|---|---|
| Jan-15 | 3000 | 5000 | Need Previous Months Oil in Tank to Calculate |
| Feb-15 | 2800 | 4000 | 2200 |
| Mar-15 | 2200 | 5000 | 1800 |
| Apr-15 | 3600 | 5500 | 1400 |
| May-15 | 4000 | 5000 | 1500 |
| Jun-15 | 4500 | 5500 | 500 |
| Jul-15 | 5400 | 5600 | 100 |
| Aug-15 | 5500 | 6000 | 100 |
| Sep-15 | 5900 | 5900 | 100 |
| Oct-15 | 5500 | 5500 | 400 |
| Nov-15 | 4700 | 5000 | 800 |
| Dec-15 | 3600 | 6000 | 1400 |

We've also calculated the number of heating degree days for each day of the week using Environment Canada data. In total for the week there have been 200 heating degree days [see Table 3 at end of document].

$$\text{Oil per HDD} = \frac{1{,}000\text{L}}{200\text{ HDDs}} = 5\text{L per HDD}$$

From those two pieces of information we now know that the building in question uses 5 L of oil for every heating degree day to heat the building.

We can do this calculating over several different periods and average them to make sure we are getting reasonably repeatable results. You probably won't get the exact same number, but you should get something fairly close as long as there have been no changes to the building or the way it is used or operates.

Keep in mind, things like school breaks, weekends, and snow days will affect the amount of energy used to heat a building.

We can also use this data to estimate exactly how much of the oil was burned on each particular day, or even use it to predict how much oil will be required in the next month.

## Natural Gas

Natural gas heating systems have the benefit of normally being separated from lighting, plug-in loads, ventilation and air conditioning loads. This means that they usually are a pretty good indication of how much energy was used for heating. Unlike oil, since natural gas comes in a pipeline and is not generally not stored in a tank on site, the amount indicated on the bill is equal to the amount of natural gas used in the period.

However, natural gas is still probably not used at a constant rate, and a monthly bill still won't give us an idea of how much natural gas was used on a daily basis.

In order to solve this problem, we can once again turn to the concept of degree days (discussed in detail in our Energy Audit: Degree Days package) to actually estimate the amount of natural gas burned on any given day based on the outdoor temperature.

Let's say we know that in a one week period in December, we know that 900m$^3$ of natural gas has been burned.

We've also calculated the number of heating degree days for each day of the week using Environment Canada data. In total for the week there have been 150 heating degree days [see Table 4 at end of document].

$$\text{Nat Gas per HDD} = \frac{900\text{m}^3}{150\text{ HDDs}} = 6\text{m}^3 \text{ per HDD}$$

From those two pieces of information we now know that the building in question uses 6m$^3$ of natural gas for every heating degree day to heat the building.

We can do this calculating over several different periods and average them to make sure we are getting reasonably repeatable results. You probably won't get the exact same number, but you should get something fairly close as long as there have been no changes to the building or the way it is used or operates.

Keep in mind, things like school breaks, weekends, and snow days will affect the amount of energy used to heat a building.

We can also use this data to estimate exactly how much of the natural gas was burned on each particular day, or even use it to predict how much natural gas will be required in the next month.

**Note: Make sure you check the meter read date on each bill. Even when billed monthly, the reading date may vary by a couple of days.**

## Electricity

Buildings where heating is provided by electricity provide an extra complication in that there is rarely any separation of heating loads from any other type of electrical load (lighting for example).

Once again, we can turn to degree days to help us find our way through it. The theory works as follows:

1. When viewed over a long period of time, the amount of energy used from day to day for non-heating loads is going to be pretty much constant. You may use a little more or less from one day to the

next, but except for exceptional events, the amount should be fairly steady. This assumes you haven't made any energy improvements to your school in that time period.

2. That would mean that any significant change in your electricity bill is related to the amount of heat required, as this will change dramatically on a daily basis.

3. If we can isolate that changing portion of electricity use, and tie it to the outside temperature at that time, we can figure out how much of the electricity is used for heat.

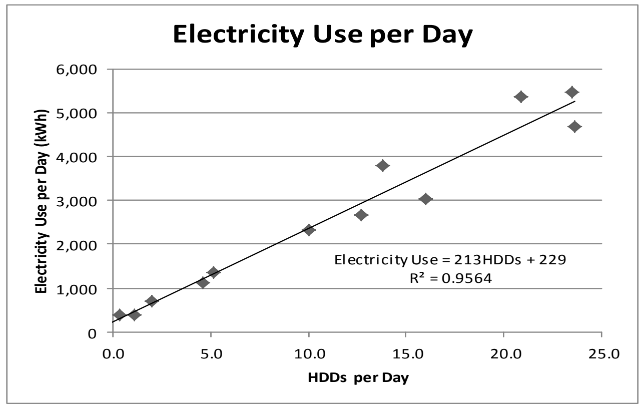
In order to solve this problem, we can once again turn to the concept of degree days (discussed in detail in our Energy Audit: Degree Days package) to actually estimate the amount of electricity used for heating on any given day based on the outdoor temperature.

To do this we need a series of electricity bills covering a period in which there hasn't been a major change to the way the building uses energy. For a school, a school year is an appropriate period to use. Any major changes are likely done in the summer, so it eliminates them from the equation.

By creating a table similar to the one in Table 5 [see end of document] we can make an estimate of daily electricity use and how much is attributable to heating. It is important to have the electricity use per day, and the HDD per day columns (which are just the electricity use and HDDs for the month divided by the number of days in the month) since it isn't a good comparison to compare January (31 days) to February (28 days).

Once we have the data in a table we can plot the 'HDDs per Day' against the 'Electricity Use per Day' (Figure 1). This gives us a graph that should hopefully form an approximate line. This line is an estimate of the amount of electricity that we would use on a given day at any number of HDDs. The slope tells us the amount of heat required per HDD, and the y-intercept tells us the amount of electricity that is not heat related (since on a day with 0 HDDs we require no heat, but still use electricity).

**Figure 1:** Graph showing relationship between Heating Degree Days per Day and Electricity Use per Day




In this case, the formula from the graph shows that on average, the building uses 229 kWh per day in non-heat related electrical loads, and 213 kWh per day for every Heating Degree Day. We can then use that rate to make a daily estimate of the amount of electricity used for heating every day, as in Table 6.

The **R-Squared Value** shown on the chart is simply a statistical value that shows us how good a fit our line is to our data. Typically any value over 0.7 is assumed to mean that there is a relationship, and any value over 0.9 is considered to be an excellent fit.

## Essential Resources

### Degree Days: The Gaia Project

http://www.thegaiaproject.ca/sites/default/files/teacher-resources/project-guides/degree-days.pdf

## Additional Resources

### R-Squared

http://en.wikipedia.org/wiki/R-squared

# Building Envelope

Instead of using energy bills, we can make an estimate of the energy use for heating by looking at the building itself. Basically, we try and make some theoretical calculations of the amount of heat that should be lost through each surface of the building.

## Heat Loss (Method 1)

Heat loss **through a surface** can be calculated using the following formula:

**Formula 1:**

$$\dot{Q} = \frac{A(T_{HOT} - T_{COLD})}{R}$$

Where:

- Q is the rate at which heat is transferred from the hot body to the cold body in Joules per second
- A is the surface area between the hot body and the cold body in $m^2$
- $T_{Hot}$ is the temperature of the hot body in $^oK$ (in Canada during winter, this will be the indoor temperature)
- $T_{Cold}$ is the temperature of the cold body in $^oK$ (in Canada during winter, this will be the outdoor temperature).
- R (called **R-value**) is the thermal insulation value in:

$$\frac{m^2 \cdot K \cdot s}{J}$$

  ◊ **Be careful here:** insulation values in Canada and the US are usually in non-SI units which means that they will not work in the above equation without some conversion. Ensure that you use SI units in your calculation.

- $T_{Hot}$ and $T_{Cold}$ are both supposed to be measured in °K rather than °C, but since we are looking at the difference between the two, the numbers will be identical.

Surface area can be found using a tape measure, ultrasonic distance metre, or by looking for the original engineering drawings of the building in question (check with the custodial staff).

Keep in mind that this will need to be done for all surfaces in a building, including walls, windows, and floors (ground temperature would the $T_{Cold}$ in this case).

After collecting all of this data, we can now estimate heat loss for any surface under any different inside and outside air temperature using the formula given above. A table such as the one in Table 7 [see end of document] could be constructed to allow you to see the heat loss through each surface. Remember to separate the surface areas into different R-values (like windows and walls).

This table only gives the rate of heat loss at a given temperature. Since temperature will most likely vary throughout the day, it is not that helpful in determining energy loss over the course of a day, month or year. Instead, we could use an average daily temperature (or weekly, or even monthly) as in Table 8 [see end of document]. We can then calculate energy loss by multiplying the heat loss in watts, by the number of hours in a day (or week, or month), to get energy loss in kWh.

Average daily, and monthly temperatures for various locations can be obtained from Environment Canada for many previous years (even 100 years ago for some locations).

Performing this calculation for every surface, for every day (or week, or year) may be tedious, so it may be quicker to calculate an average building R-value that accounts for all the different surfaces. To do this, we calculate a weighted average as in Table 9 [see end of document].

The weighted average simply weights each R-value by the amount of the area in the building that it is applicable to. So in this case,

We can then use this weighted R-value and the total building surface area, along with daily average temperature to more quickly calculate energy loss. So using a building surface area of $220m^2$, the weight average R-Value of 0.73, and an inside temperature of 21°C, we can get something like Table 10 [see end of document].

## Heat Loss (Method 2)

A second method exists for calculating the rate of heat loss from a room. This involves letting a room cool down over a known period of time, and calculating the amount of energy that was lost in that time period.

We can use the following formula to achieve this:

**Formula 2:**

$$\dot{Q} = \frac{mc\Delta T}{t}$$

Where:

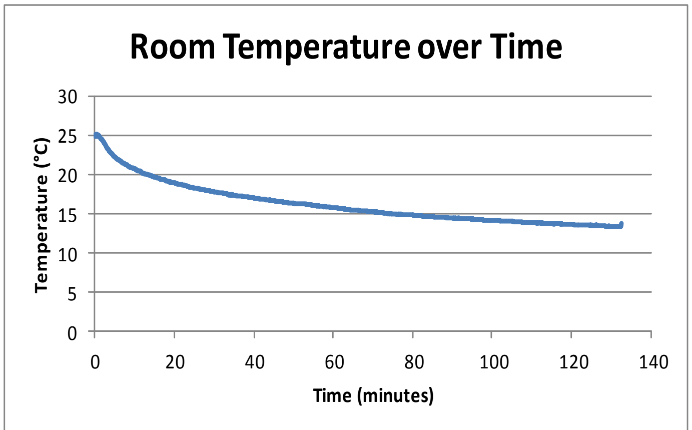
- Q is the rate at which heat was lost in Joules per second
- m is the mass of air in the room in question
- C is the specific heat capacity of air. It changes a little bit with temperature and pressure, but you can essentially assume it is a constant at 1 kJ/kg-°K
- ΔT is the change in temperature over the measured time period in °K (which is always the same as °C)
- t is the time period over which the temperature was measured in seconds.

In order for this method to work, it is essential that all sources of heat to the room are shut off (or at least the energy input is known). Obviously if we have an unknown amount of energy going into the room while trying to determine the rate that heat is lost, it'll be pretty hard to find an answer!

1. Ensure that all sources of heat to room are off (or as minimized as possible). This may mean turning thermostats down, switching off heaters, blocking air vents, and blocking gaps underneath doors.
2. This will not ensure that no heat is added to the room, but will minimize it. Some heat may transfer into the room from neighbouring rooms through the walls, floor and ceiling. However, since the temperature difference between those rooms and the room you are measuring is likely very small or zero initially, this rate of heat transfer is likely to be negligible in the short term — see **Formula 1**. If you allow the room to cool down significantly, this rate of heat transfer from neighbouring rooms will increase significantly and distort your results.
3. Record the room temperature over a short period of time (say 15 minutes). To ensure accuracy, you may want to be out of the room to avoid the impact of your body heat on the results.

For example, assume we proceeded as described above and came up with the data shown in Figure 2.

**Figure 2:** Temperature data from a cooling room




In the first 10 minutes the temperature drops from 25°C to 20.7°C—a decrease of 4.3°C. If the room measures 4m x 4m x 2.5m, using Formula 2:

$$\dot{Q} = \frac{mc\Delta T}{t}$$

$$\dot{Q} = (4\text{m} \times 4\text{m} \times 2.5\text{m})\left(\frac{1.23\text{kg}}{\text{m}^3}\right)\left(\frac{1.006\text{ kJ}}{\text{kg}\cdot\text{K}}\right)(4.3°\text{K})\left(\frac{1}{600\text{s}}\right)$$

$$\dot{Q} = 40\text{m}^3\left(\frac{1.23\text{kg}}{\text{m}^3}\right)\left(\frac{1.006\text{ kJ}}{\text{kg}\cdot\text{K}}\right)(4.3°\text{K})\left(\frac{1}{600\text{s}}\right)$$

$$\dot{Q} = \frac{0.354\text{kJ}}{\text{s}} = \frac{354\text{J}}{\text{s}} = 354\text{W}$$

So this room is losing 354W of heat under the current conditions.

This only tells us heat loss from a single room under a single set of conditions. It would only apply to other rooms if they were identical in size and construction. However, we can get some information from it that would allow us to apply it to an entire building.

Firstly, if we look at **Formula 1**, we can see that the rate of heat loss is directly proportional to the temperature difference between indoors and outdoors. So, on a warmer day, when the temperature difference is half what it was on the day this data was collected, we know that the rate of heat loss will be half.

We could also look at the slope of the graph at any given temperature to calculate our instantaneous rate of heat loss. For example, at 18°C, the slope of the graph is –0.003°C / s. Again using Formula 2:

$$\dot{Q} = (4\text{m} \times 4\text{m} \times 2.5\text{m})\left(\frac{1.23\text{kg}}{\text{m}^3}\right)\left(\frac{1.006\text{ kJ}}{\text{kg}\cdot\text{K}}\right)(0.003°\text{K})\left(\frac{1}{1\text{s}}\right)$$

$$\dot{Q} = 40\text{m}^3\left(\frac{1.23\text{kg}}{\text{m}^3}\right)\left(\frac{1.006\text{ kJ}}{\text{kg}\cdot\text{K}}\right)(0.003°\text{K})\left(\frac{1}{1\text{s}}\right)$$

$$\dot{Q} = \frac{0.148\text{kJ}}{\text{s}} = \frac{148\text{J}}{\text{s}} = 148\text{W}$$

This is less than we previously calculated, which makes sense, since we were looking at heat loss at a lower temperature.

Secondly, we can actually use the data we collected to determine the average R-Value of the exterior walls and then use **Formula 1** to figure out heat loss on any given day. We could also assume that the average R-Value of the exterior walls are the same for all similar rooms. This method is discussed in **Finding R-Value**.

# Finding R Value

## Inspection

Different materials have different R-values, and are dependent on the thickness of the insulation. So if you know what a surface is made of, it is easy to look up the R-value for that particular surface and use it in your calculations. It also enables you to quickly see the impact of making changes to the construction of a building.

R-Values can be quickly found from many resources, and are typically given in non-SI units. **Ensure that you use SI units, or do the appropriate unit conversion to obtain the correct results.** The Wikipedia link provided in the essential resources below provides R-values in both SI and non-SI units.

SI R-Values are given per metre of insulation. It is unlikely that you will actually have one metre of the material in your construction, so you will have to scale accordingly.

For example, the SI R-Value of brick is given as :

$$0.76\frac{m \cdot {}^{\circ}K}{W}$$

If we have 10cm of brick in our wall, the R-Value of that brick is:

$$\mathrm{R-Value} = 0.76\frac{\mathrm{m} \cdot {}^{\circ}\mathrm{K}}{\mathrm{W}} \times 0.1\mathrm{m}$$

$$\mathrm{R-Value} = 0.076\frac{\mathrm{m}^2 \cdot {}^{\circ}\mathrm{K}}{\mathrm{W}} = 0.076\frac{\mathrm{m}^2 \cdot {}^{\circ}\mathrm{K} \cdot \mathrm{s}}{\mathrm{J}}$$

R-Values can be added together where multiple materials are together side by side.

## Wall Temperatures

Most of the time, we do not know exactly what a surface is made of and how thick it is. It is hard to determine the thickness of glass panes already installed, or know the gas composition in between panes, and we obviously can't see through walls.

Instead we can make and estimate of the R value of a surface using the graph shown in Figure 2 [see end of document], and by making a few measurements.

Using the various temperature probes available, we can take readings of the appropriate temperature and use the graph to make an estimate of the R value of a given external surface. It is essential that inside and outside temperatures be taken on the same day, otherwise they aren't related to each other.

Avoid taking measurements when a surface is in direct sunlight, and try taking several readings along the same surface. It is also worthwhile taking readings on several different days, and averaging them to get an appropriate estimate of the R Value.

Say we have a room where the inside air temperature is 22°C, the inside wall temperature is 21°C, and the outside wall temperature is 4°C. The temperature difference between the inside wall and inside air temperature is:

22°C — 21°C =1°C

And the temperature difference between the inside wall and the outside wall is:

21°C — 4°C = 17°C

We can use Figure 2 to show that the approximate R-Value of that wall is somewhere between R10 and R15. We could estimate it is approximately R13.

## Measuring Experimentally

To do this, we just rearrange **Formula 1** to calculate R (since we already know Q from **Formula 2)**

**Formula 3:**

$$\mathrm{R} = \frac{\mathrm{A}(\mathrm{T_{HOT}} - \mathrm{T_{COLD}})}{\dot{\mathrm{Q}}}$$

Where:

- $T_{Hot}$ is the average indoor temperature during your experimental data collection

Let's go back to our previous example where the rate of heat loss was 354W as the temperature fell from 25°C to 20.7°C (average temperature is 22.9°C). The exterior wall to the room measures 4m x 2.5m, and let's say the outside air temperature was –10°C. Then:

$$R = \frac{(4\text{m} \times 2.5\text{m})(22.9℃ - {}^{-}10℃)}{354\text{W}}$$

$$R = \frac{(10\text{m}^2)(32.9\text{K})}{354\,\frac{\text{J}}{\text{s}}} = 0.93\frac{\text{m}^2 \cdot \text{K} \cdot \text{s}}{\text{J}}$$

Again, for a more accurate number, we can use the slope method shown previously to calculate our instantaneous heat loss, and then use that number in Formula 3 exactly as shown above.

### Essential Resources

**R-Value (Insulation)**
http://en.wikipedia.org/wiki/R-value_(insulation)

# RETScreen

Software tools such as RETScreen can also be used to calculate building energy loss due to heat. RETScreen is a free program produced by Natural Resources Canada, and used to determine the feasibility of clean energy products.

It is widely used, and a very capable program, although it can take some time to become familiar with it.

### Additional Resources

**RETScreen Clean Energy Project Analysis Software**
http://www.retscreen.net/

# Converting to Common Units

We can convert litres of heating oil burned, and $m^3$ of natural gas burned to kWh, as they contain standard amounts of energy (or close to it).

- Heating Oil = 38.5 MJ / L = 10.7 kWh / L
- Natural Gas = 38.5 MJ / $m^3$ = 10.7 kWh / $m^3$
- 1 GigaJoule (GJ) of anything = 227.8 kWh
- 1 MegaJoule (MJ) of anything = 0.278 kWh

This will make it easier to directly compare oil, natural gas, electricity or any other source of energy consumption.

# Glossary

**Building Envelope**
The outer shell of a building protecting the indoor environment. The more sealed a building, the slower the rate of heat loss will be.

**Heating Degree Days**
Equivalent to having to heat building by 1°C for an entire day.

### R-Squared

In statistics, this is also known as the coefficient of determination. It is a statistical value that shows us how good a fit our line is to our data. Typically any value over 0.7 is assumed to mean that there is a relationship, and any value over 0.9 is considered to be an excellent fit.

### R-Value

A measure of thermal resistance, or a measure of well a material resists heat loss.

# Useful Values

### Heating Oil

38.5 MJ / L = 10.7 kWh / L

### Natural Gas

38.5 MJ / $m^3$ = 10.7 kWH / L

### Energy

1kWh = 3,600,000 Joules

1 Wh = 3,600 Joules

### Power

1 hp = 746 Watts

# Energy Audit: Heating

**Table 3:** Estimate of daily oil usage using HDDs

| Date | Average Daily Temperature (°C) | HDDs (Based on 18°C Balance Temperature) | Percentage of Heating Degree Days In Period (%) |
|---|---|---|---|
| Jan-15 | -21 | 39 | 19% |
| Jan-16 | -16 | 34 | 16% |
| Jan-17 | -11 | 29 | 14% |
| Jan-18 | -5 | 23 | 11% |
| Jan-19 | -5 | 23 | 11% |
| Jan-20 | -11 | 29 | 14% |
| Jan-21 | -12 | 30 | 14% |
| **Total** | | **207** | **100%** |

**Table 4:** Estimate of daily natural gas usage using HDDs

| Date | Average Daily Temperature (°C) | HDDs (Based on 18°C Balance Temperature) | Percentage of Heating Degree Days In Period (%) |
|---|---|---|---|
| Jan-15 | -21 | 39 | 19% |
| Jan-16 | -16 | 34 | 16% |
| Jan-17 | -11 | 29 | 14% |
| Jan-18 | -5 | 23 | 11% |
| Jan-19 | -5 | 23 | 11% |
| Jan-20 | -11 | 29 | 14% |
| Jan-21 | -12 | 30 | 14% |
| **Total** | | **207** | **100%** |

**Table 5:** Electricity use per day and heating degree days per day

| Electricity Bill Covers | Days in Billing Period | Electricity Used (kWh) | Electricity Used per Day (kWh/day) | HDDs | HDDs per Day |
|---|---|---|---|---|---|
| 01-Aug to 31-Aug | 31 | 11,696 | 377 | 34 | 1.1 |
| 01-Sep to 30-Sep | 30 | 33,931 | 1,131 | 137 | 4.6 |
| 01-Oct to 31-Oct | 31 | 82,801 | 2,671 | 393 | 12.7 |
| 01-Nov to 30-Nov | 30 | 113,897 | 3,797 | 415 | 13.8 |
| 01-Dec to 31-Dec | 31 | 144,703 | 4,668 | 732 | 23.6 |
| 01-Jan to 31-Jan | 31 | 169,257 | 5,460 | 729 | 23.5 |
| 01-Feb to 28-Feb | 28 | 150,096 | 5,361 | 585 | 20.9 |
| 01-Mar to 31-Mar | 31 | 93,910 | 3,029 | 495 | 16.0 |
| 01-Apr to 30-Apr | 30 | 69,658 | 2,322 | 300 | 10.0 |
| 01-May to 31-May | 31 | 42,275 | 1,364 | 160 | 5.2 |
| 01-Jun to 30-Jun | 30 | 21,011 | 700 | 60 | 2.0 |
| 01-Jul to 31-Jul | 31 | 11,731 | 378 | 10 | 0.3 |
| **Total** | **365** | **921,539** | **2,525** | **4050** | **11.1** |

**Table 6:** Estimate of daily electricity usage using HDDs

| Date | Average Daily Temperature (°C) | HDDs (Based on 18°C balance temperature) | Elecriticty used for Heating (kWh) |
|---|---|---|---|
| Jan-15 | -21 | 39 | 18,731 |
| Jan-16 | -16 | 34 | 31,128 |
| Jan-17 | -11 | 29 | 57,740 |
| Jan-18 | -5 | 23 | 112,813 |
| Jan-19 | -5 | 23 | 220,411 |
| Jan-20 | -11 | 29 | 440,823 |
| Jan-21 | -12 | 30 | 881,645 |
| **Total** | | **207** | **1,763,291** |

**Table 7:** Calculating heat loss through individual surfaces under given conditions

| Surface | Exterior Material | Surface Area ($m^2$) | R Value ($ft^2$-°F-h/BTU) | R Value ($m^2$-°C-/W) | $T_{Hot}$ (°C) | $T_{Cold}$ (°C) | Heat Loss (W) |
|---|---|---|---|---|---|---|---|
| North Wall | Brick | 100 | 5 | 0.88 | 21 | -10 | 3515 |
| North Windows | Glass | 10 | 1.5 | 0.26 | 21 | -10 | 1172 |
| South Wall | Brick | 95 | 4 | 0.71 | 21 | -10 | 4174 |
| South Windows | Glass | 15 | 1 | 0.18 | 21 | -10 | 2637 |

**Table 8:** Calculating energy loss using average daily temperature

| Surface | Exterior Material | Surface Area ($m^2$) | R Value ($ft^2$-°F-h/BTU) | R Value ($m^2$-°C-/W) | $T_{Hot}$ (°C) | $T_{Cold}$ (°C) | Heat Loss (W) | Daily Energy Loss (kWh) |
|---|---|---|---|---|---|---|---|---|
| North Wall | Brick | 100 | 5 | 0.88 | 21 | -10 | 3515 | 84.4 |
| North Windows | Glass | 10 | 1.5 | 0.26 | 21 | -10 | 1172 | 28.1 |
| South Wall | Brick | 95 | 4 | 0.71 | 21 | -10 | 4174 | 100.2 |
| South Windows | Glass | 15 | 1 | 0.18 | 21 | -10 | 2637 | 63.3 |

**Table 9:** Calculating building weighted average R-Value

| Surface | Exterior Material | Surface Area ($m^2$) | R Value ($ft^2$-°F-h/BTU) | R Value ($m^2$-°C-/W) |
|---|---|---|---|---|
| North Wall | Brick | 100 | 5 | 0.88 |
| North Windows | Glass | 10 | 1.5 | 0.26 |
| South Wall | Brick | 95 | 4 | 0.71 |
| South Windows | Glass | 15 | 1 | 0.18 |
| | **Total** | 220 | **Weighted Average** | 0.73 |

**Table 10:** Calculating daily heat loss

| Date | Average Daily Temperature (°C) | Heat Loss (Watts) | Energy Loss (kWh) |
|---|---|---|---|
| Jan-15 | -21 | 12666 | 304 |
| Jan-16 | -16 | 11158 | 268 |
| Jan-17 | -11 | 9650 | 232 |
| Jan-18 | -5 | 7841 | 188 |
| Jan-19 | -5 | 7841 | 188 |
| Jan-20 | -11 | 9650 | 232 |
| Jan-21 | -12 | 9952 | 239 |
| **Total** | | | **1650** |

## Figure 2: R-Value Estimation