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SKETCHBOX LESSON 4_v1.01:
Carbon Emissions

Next Generation Science Standards (https://www.nextgenscience.org/)

Content Standards

HS-LS2-7 Ecosystems: Interactions, Energy, and Dynamics
Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.*

HS-ETS1-4 Engineering Design
Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

Science and Engineering Practices
2. Developing and using models
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Lesson metatags
building design, computer model, data analysis, efficiency, electricity, energy, energy conservation, energy economics, heating and cooling, HVAC, kwh, natural gas, NG, simulation, utility rates, carbon emissions, greenhouse gas equivalents

Student materials begin on the next page.

SKETCHBOX™ LESSON 4_v1.01: Carbon Emissions

Student Activity and Response Guide

Introduction

Energy use in buildings results in the emission of large amounts of carbon dioxide. This is especially true for natural gas used to heat space or hot water and for most of the electricity currently produced in the United States. Making a building more energy efficient is an excellent way to reduce these emissions. Since electricity generation is slowly transitioning to low-carbon energy sources some building systems that burn natural gas or other hydrocarbon fuels are being replaced with electric systems that can do the same functions, a change called electrification. Examples of this are to use a heat pump for space heating and cooling or on-demand electric water heaters.

Emissions are often reported as carbon dioxide equivalents

While burning carbon-based fuels creates carbon dioxide, this is not the only emission that can cause environmental harm. Unburned natural gas and nitrogen oxides are examples of other emissions that can negatively impact the environment. To estimate the total impact of emissions from a particular process values are often reported as kilograms of carbon dioxide equivalents, written as $kg\text{-}CO_2e$. This value includes the amount of carbon dioxide emitted and also a weighted contribution for other pollutants, some of which are more environmentally damaging, for the same amount, than carbon dioxide.

Sketchbox calculates carbon emissions results

Carbon emissions for the generation of electricity vary from location to location due to the primary energy source (e.g. wind, solar, natural gas, coal, biomass, nuclear). For example in Illinois sketchbox models carbon emissions for electricity as 0.371 $kg\text{-}CO_2$ eq for each kilowatt hour (kWh) while for neighboring Wisconsin the value is 0.633 $kg\text{-}CO_2$ eq / kWh. The first step in reducing carbon emissions is usually to use energy more efficiently through energy efficient building construction, careful siting, appropriate scheduling, and use of energy efficient lights and equipment. This matters because every kWh of
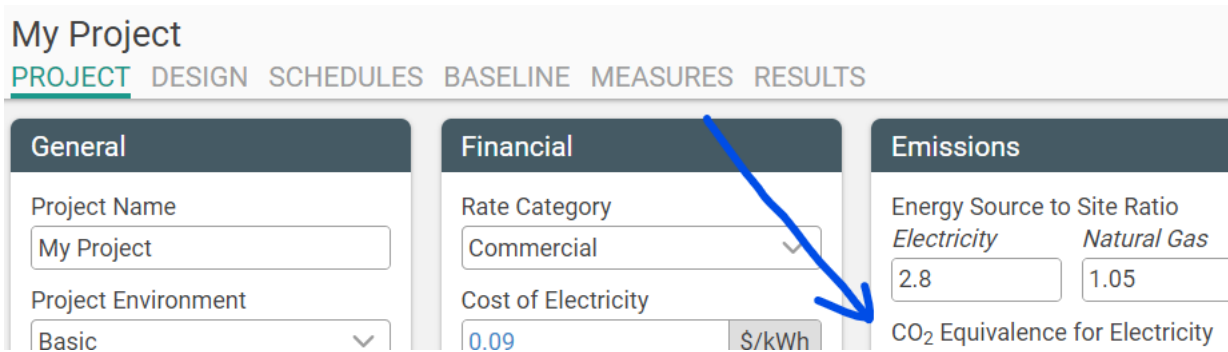
electricity or therm of natural gas that is not needed will account for zero g-CO_2 eq per kWh or therm, the best we can do! After that, carefully selecting the types of mechanical systems may also have an impact.

Calculating carbon emissions

1. Access the web address: https://www.sketchbox.io/login

2. Login to sketchbox using your account.

3. When sketchbox opens use the "project" tab to name your project. Then, record the CO_2 equivalence for electricity and natural gas from the "emissions" table. These values are specific to the location, in this case Chicago.

Electricity (kg of CO_2e/kWh): **   Natural gas (kg of CO_2e/kWh): **

4. Switch to the design tab to note the building type and area, but you do not need to make any changes. We will model a medium office building.

5. Switch to the results tab and fill in the annual electric and natural gas consumption in the top row of table 1 (located below).

Table 1

Building model	Annual electric consumption (kWh)	Annual natural gas consumption (therm)	Annual emissions Kg-CO$_2$e
Baseline	*	*	*
Energy efficient lights	*	*	*
Demand control ventilation	*	*	*
Move to Madison, WI	*	*	*

6. With the electricity (kWh) and natural gas (therm) values just recorded it is possible to calculate the total annual carbon emissions for the building. Multiply the annual electric consumption (kWh) by the kg-CO$_2$e/kWh value you recorded for electricity in step 3. Record the result here: **

7. Multiply the annual natural gas consumption from table 1 by the kg-CO$_2$e/therm value from step 3 and record the result here: **

8. Add together the CO$_2$e emissions totals from steps 6 and 7 and record that result in the top row of table 1 in the annual emissions column. This number is the total amount of carbon dioxide equivalent emissions produced by the energy used for the building over a typical year. In the next steps we will explore how this emission value can be reduced.

9. Interior lighting power describes how much electric power is needed, per square foot, to provide light for tasks typically done in a building. This value can vary a lot based on how much light is needed in a particular type of building and with the type of lighting technology. More efficient lighting may cost more to install, but the extra cost may more than pay for itself in energy savings.

10. Switch to the baseline tab and find the lighting section in the bottom row (see image below). Reduce the interior lighting power from 0.711 to 0.45 W/ft^2.

Lighting

Interior Lighting Power
0.711 | W/ft²

Reduction from Controls
22 | %

Reduction from Task Tuning
0 | %

Daylighting

11. Switch back to the results tab and add the new values for electricity and natural gas consumption to the second row of table 1. Then, calculate the kg-CO_2e value in the same way you did for the first row.

12. Another way to reduce the energy use by buildings is to only provide fresh air when it is needed to meet the needs of building occupants. For example, it saves energy to not provide fresh air for a room if no one is in the room. This feature of building controls is called demand control ventilation.

    Switch to the baseline tab and change the interior lighting power back to 0.711 W/ft². Then, find the ventilation section in the bottom row and change the "demand control ventilation" setting from no to yes.

Ventilation

Ventilation Rate
17 | CFM/person

Ventilation Minimum Flow Fraction
0

Air-Side Economizer
Yes

Demand Control Ventilation
No

13. Change to the results tab and record electricity and natural gas consumption values in the third row of table 1. Then, calculate the annual carbon emissions as you did for the previous rows.

14. Comment on the carbon emission reductions from these two strategies (efficient interior lighting, demand control ventilation). Is the carbon emissions savings significant? What barriers might prevent these changes from being put in place?
*

15. As mentioned, carbon emissions from electricity depend on the primary energy source used to generate electricity. In Illinois a substantial amount of electricity is generated by nuclear power plants so carbon emissions for electricity in Illinois are relatively low. In neighboring Wisconsin there is less nuclear electricity and more generation from coal and natural gas.

    Switch to the project tab and change locations from Chicago, Illinois to Madison, Wisconsin. The natural gas kg-CO_2e/therm value is the same as in step 3, but the electricity value will be different. Record the new values.

Electricity (kg of CO_2e/kWh): **   Natural gas (kg of CO_2e/kWh): **

16. Return to the results tab and use the new annual summary values for electricity and natural gas for the last row in table 1. Then, calculate the final annual carbon emissions value.

17. What do you notice about the carbon emissions for the building in Madison compared to Chicago? Summarize the reasons you believe cause this difference.
*

Additional resources for this topic
The U.S. Energy Information Administration provides energy profiles for every state. These can be accessed from the link below and selecting the "electricity" tab shows a detailed chart of the primary energy sources used for electricity generation in that state.
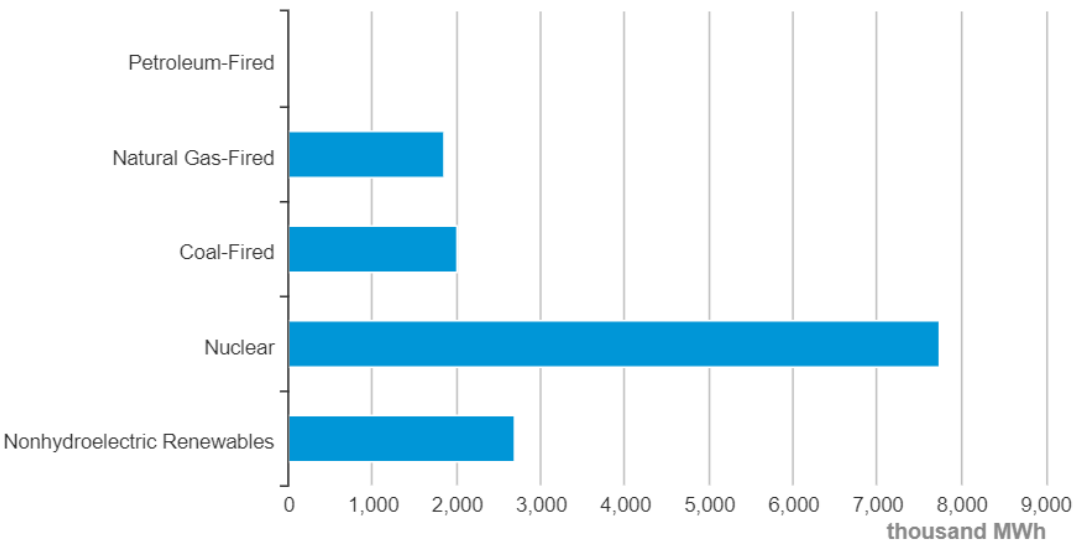
EIA state energy profiles:
https://www.eia.gov/state/

Example for Illinois:

There are also many green building ideas and strategies included in the LEED process, Leadership in Energy and Environmental Design, from the U.S. Green Building Council: https://www.usgbc.org/leed