Title of Paper: Residential Home Insulation Efficiency

(Personal Details intentionally omitted)

Residential Home Insulation Efficiency

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Abstract

Energy inefficiency is a major contributing factor to climate change, the number one issue facing the world today. The North American Insulation Manufacturers Association has estimated that 90% of U.S. homes today are under-insulated, which results in unnecessary electricity production, causing the release of harmful gasses and a rise in climate change. The purpose of this experiment was to determine which type of insulation material was the most effective. Model homes were built out of wood to be put in an oven and refrigerator to determine which insulating material reacted the best to reach a level of a chosen room temperature of 78.3 degrees Fahrenheit. The average temperature of each room was compared to find the most efficient material. To maintain an ambient temperature in hot temperatures, it was found that the most efficient material is Thick Havelock. For cool temperatures, it was found that Hemp Wool is more efficient. The information of this project can be used by the public to make informed choices on insulating materials that make their homes more efficient while keeping houses at the desired temperature. With the information collected on these different materials, the next steps of this project will be to evaluate additional properties of insulation materials like moisture intake and sound-blocking.

Residential Home Insulation Efficiency

Energy inefficiency is a major contributing factor to climate change, the number one issue facing the world today (Introcaso, 2018). This inefficiency exacerbates the detrimental effects of electricity generation, particularly the emission of harmful gasses into the environment. These environmental effects result in a decrease in organism populations and abnormal weather changes ("U.S. energy system factsheet," n.d.). On a larger scale, climate change affects every organism on the planet and has adverse impacts on human health and lifestyle. While climate change is a profound problem, there are measures that individuals can undertake to mitigate its effects, including using renewable resources, using LED light bulbs, spreading awareness, reducing food/water waste, and making lifestyle changes.

An analysis of electricity consumption is another way to help combat the negative impact of climate change. Electricity consumption is split into different sectors in America: Commercial (18.1%), Industrial (32.4%), Residential (21.2%), and Transportation (28.2%) ("U.S. energy system factsheet," n.d.). Within the residential sector, a home's electricity bill is based on heating and cooling, water heating, lighting and refrigeration, and electronic device usage (Bailey, n.d.). Heating and cooling make up more than 50% of an electricity bill, making it important to use efficient materials and plans to reduce consumption ("12 reasons your energy bill is going up," 2020).

Utilizing efficient residential insulation can decrease the costs of heating and cooling a house, resulting in reduced electricity bills and aiding the environment (Bailey, n.d.). The North American Insulation Manufacturers Association has estimated that 90% of U.S. homes today are under-insulated ("12 reasons your energy bill is going up," 2020). Since a substantial amount of energy escapes the structure due to inadequate insulation, more energy is required to keep the structure at a certain temperature, which in turn necessitates more energy generation and the resulting adverse impacts of climate change.

This inefficiency of insulation materials can lead to many environmental issues, economic problems, and negative effects on an individual's health ("Detrimental effects of poor insulation installation," 2018). Economically, higher electricity bills are produced when insufficient insulation does not entirely protect the home from varying ambient temperatures. The United States Environmental Protection Agency has estimated that 15% of the costs from heating and cooling, almost $200, can be saved annually by using sufficient insulation (Scottberg, 2019). Environmentally, producing electricity creates harmful gasses such as methane and nitrous oxide, which contribute to climate change ("Overview of Greenhouse Gasses," n.d.). If Americans could reduce the amount of electricity they use, they could simultaneously save money and decrease the production of these harmful gasses. In addition to the environmental and economic effects, health concerns also exist since some insulation materials can be dangerous to the human body ("What you need to know about how insulation affects health," 2021). An example of a toxic material is polyurethane foam, a common home insulator. Even though this material is used in homes, polyurethane can lead to types of cancer, a weakened nervous/immune system, negative neurological outcomes, and many other medical consequences, leading to higher hospitalization and death rates (Kerr, n.d.).

Different materials work with varying efficiency rates (see Appendix A). Out of all the materials, professionals say that spray foam insulation is the most efficient (Miller, 2019). However, this material may lead to issues such as water damage, shrinking or the material not filling in all cavities (Miller, 2019). Due to the variability in the degrees of effectiveness of the materials, many studies have been carried out to find the best insulation type (Rooks, 2020). An example of such an experiment was by a scientist who compared the effectiveness of different insulation materials, including fiberglass, cellulose, ThermaCork, and foams. She concluded that ThermaCork was the best insulator despite it being a more uncommon material (Rooks, 2020). However, ThermaCork is not commonly used today, thus reducing the applicability of the results.

In this project, the most effective insulation material which could keep a constant ambient temperature was found, which was Hemp Wool for cooling and Thick Havelock for heating. In contrast to using ThermaCork, this updated experiment studied the efficiency of insulation materials that are commonly used in homes in the United States today that were suggested for testing by multiple insulation technicians. To do this, ten model houses with different insulation materials were subjected to heating and cooling cycles to replicate the changes that a typical home would realistically experience. Each model included a thermometer that measured the temperature inside the house as the temperature was changed, which helped the researcher determine the ability of the insulating material to maintain the temperature inside the model. The independent variable was the type of insulation material used. The dependent variable was the temperature inside the home after the thirty-minute interval of heating or cooling had been completed.

Method

The handling instructions in the Material Safety Data Sheets were rigorously adhered to. When using the 2546759 Power Grab Express Tub Surround Construction Adhesive, inhalation, skin/eye contact, and ingestion were avoided. The different insulation materials were handled with care and awareness since each of them had risks regarding inhalation, ingestion, and skin/eye contact. Such material is fiberglass, as cancer is an increased chronic risk when working with it. For this reason, the researcher wore a mask throughout its handling. These insulation materials were all disposed of by the researcher's local waste authority to make sure the materials were safely being handled. Anyone who was in contact with any insulation material or wood equipment wore the correct personal protective equipment (PPE). A mask was required around insulation materials since the dust from most insulation materials can be damaging to the human body if it was inhaled through the mouth or nose. The body was covered, so that no skin was visible and contactable, to prevent skin irritation and possible splinters. Having access to the appropriate first aid materials was critical if exposure to any hazardous material occurred, so a first aid kit was kept handy.

Materials

- (6) Pine Wood sheets 14”x14”x0.5”
- (1) Ball Pein Hammer
- (50) 3 1/2-inch nails 16-d
- (1) Traditional Hand Saw
- (1) Refrigerator
- (1) Oven
- (1) Mercury Thermometer
- (1) 12” Ruler
- (1) Wooden Pencil
- (1) Computer
- (1) Stopwatch
- (1) 10-Ounce 2546759 Power Grab Express Tub Surround Construction Adhesive
- (1) 8-Ounce Gorilla Wood Glue

- Insulation Materials
  - (6) Cellulose Insulation Panel 12’x12’x0.5’
  - (6) Sprayfoam Insulation Panel 12’x12’x0.5’
  - (6) Formaldehyde-free™ Fiberglass Insulation Panel 12’x12’x0.5’
  - (6) Mineral Rock Wool Insulation Panel 12’x12’x0.5’
  - (6) Thick Havelock Insulation Panel 12’x12’x0.5’
  - (6) Thin Havelock Insulation Panel 12’x12’x0.5’
  - (6) Hemp Wool Insulation Panel 12’x12’x0.5’

Procedures

Building the model homes

The first part of this project was to build the model home, which served as the base of the insulation materials to imitate a house design (see Appendix B). To do this, the researcher first placed one pinewood sheet on the workspace as a base for the model home. Next, the researcher aligned another of the pinewood sheet pieces vertically onto the base’s edge. A staple gun was then used to attach the two pieces by the corner. The researcher repeated this step as she attached the other three pieces onto the other edges of the base. The researcher then marked 0.0127 meters from each side of the four walls and drew a square on the carpentry using those marks with a pencil. The researcher applied glue on one face of each insulation material. Soon after the researcher applied the glue, they placed one insulation block on every wall of the model home and waited 15 minutes for the glue to completely dry. The researcher took the extra insulation block remaining and marked the panel’s measurements to be 12”x12” using a ruler and pencil, and then cut out the panel. She then applied glue to the insulation. The researcher measured in from the outside next to 0.5” of the remaining pinewood sheet and marked this measurement with a pencil. Afterward, the researcher drew a line accordingly to form a square in the middle. When they were done with this, the researcher glued the insulation material inside the square and waited 15 minutes for the glue to completely dry. Finally, the researcher placed the remaining pinewood sheet on top of the model home, making sure it was carefully aligned. After the first model house was complete, the researcher repeated all the steps to make nine more model homes and used the different types of insulation materials for each.

Testing the insulation materials at a cool temperature

After the researcher had built all the insulated homes, it was time to test the efficiency of the insulation materials with a refrigerator and its cold temperature. The first step was to move all model homes to an area with an empty refrigerator, so the materials could efficiently be accessed. When the items could be accessed easily, the researcher set the refrigerator to 20° Fahrenheit using the controls. While the fridge cooled, the researcher picked one of the model homes previously built and took off the top cover. They placed a thermometer in the model and then placed the lid back on. The model was ready to go into the cooling system, so the researcher opened the refrigerator, placed the model home inside, then closed it securely. They immediately started a thirty-minute stopwatch so the box could cool. When thirty minutes had elapsed, the researcher opened the refrigerator and took the model out. The researcher also removed the top cover, and then the thermometer from the wooden home. She repeated the steps to test the insulations under a cool temperature with the rest of the materials by following the same steps as they had completed for the first.

Testing the insulation materials at a hot temperature

After testing the cooling of the insulation materials, the researcher was ready to test the insulation in heated temperatures with an oven. The first step was moving all the model homes near an empty oven and keeping a stopwatch ready for accurate, efficient results. The researcher set the oven to 120° Fahrenheit using the controls on the oven they were using. The researcher picked one of the model homes and removed the top cover. The removal of the top cover allowed the researcher to place the thermometer in the model home and then place the cover back on top. The box was ready to be heated, so they opened the oven and placed the model inside. The researcher then securely closed the oven. When the model home was ready for the heat, they started the thirty-minute stopwatch. When thirty minutes had passed, the researcher opened the oven and took the model out. After removing the top cover and recording the temperature, they repeated the heating portion of the experiment for the rest of the models they had created.

Results

The researcher recorded the temperature of the model home in the heating and cooling environment every five minutes till thirty minutes had elapsed. This was repeated three times for different trials, but the independent variables of each trial remained constant. The means of the three trials for each material were recorded.

Figure 1 shows a visual representation of the mean of the different insulation materials when they were being heated. The bar's length portrays the temperature, which can be found on the bottom of the graph horizontally, of each insulation material, vertically. The standard deviation of the means is 16.7. This graph also compares the means to the chosen room temperature.

Figure 1

Means of Temperature for Heated Homes After 15 Minutes

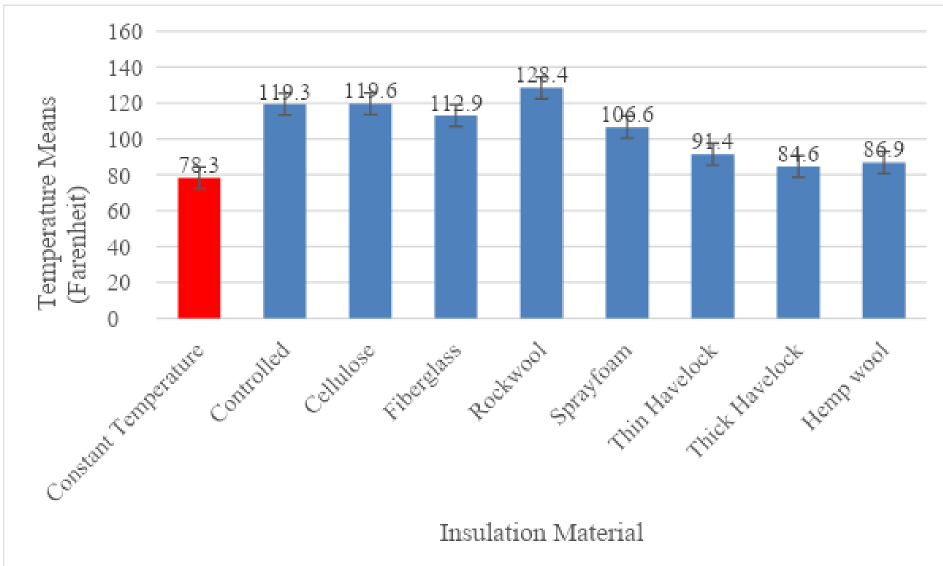
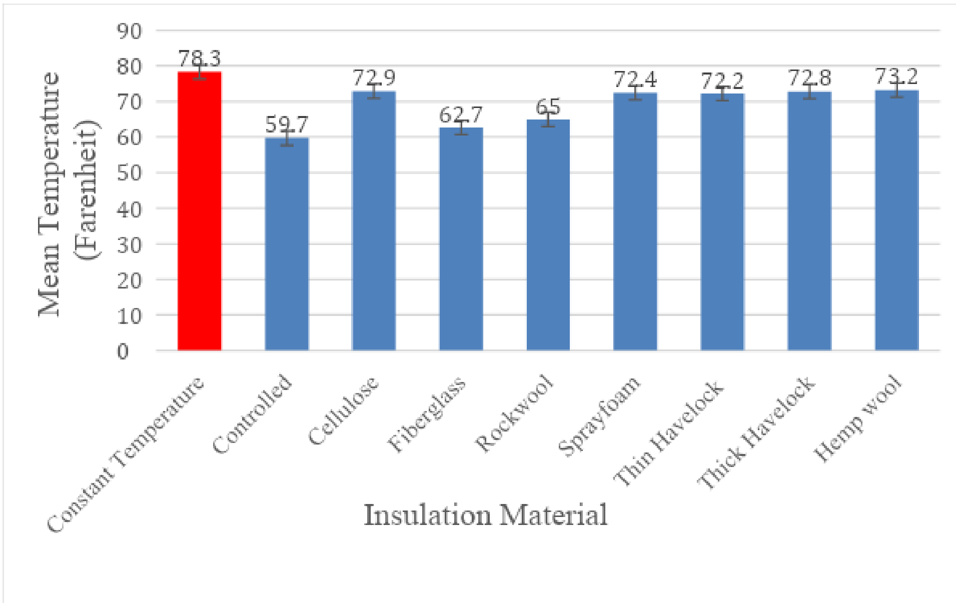


Figure 2 shows the insulation materials average when they were faced with cooling by the refrigerator. The graph is organized so that the length of the bar, shown on the bottom horizontally, represents the temperature mean of the insulation material, which can be found on the x-axis. The standard deviation of the means was 6.0. The means were compared to the chosen room temperature visually in this graphic model.

Using the data from Figure 1 and Figure 2, an Analysis of Variance, or ANOVA, was performed to determine if there was a statistical difference between the different means derived throughout the experimental process. The test was done twice, for heating and for cooling separately. The ANOVA procedure tested both the null and alternative hypotheses of the testing in the experiment. This test confirmed that the alternative hypothesis was correct, and the results were significant.

Figure 2

Means of Temperatures for Cooled Homes After 15 Minutes



Discussion

In this experiment, various insulation materials were tested to determine which type was the most efficient in different temperature environments. A model home was inserted into a refrigerator and an oven, starting with a constant initial temperature. The hypothesis of this experiment was that when the different types of insulation are tested for their efficiency, the spray foam will be the most efficient since it fills all spaces and acts as an air barrier. This hypothesis was not supported since the results portrayed that Thick Havelock is more efficient for heating than spray foam insulation. Also, it was found that Hemp Wool is more efficient when it comes to cooling compared to spray foam insulation. This conclusion was derived because Thick Havelock, which had the average mean of 86.6 degrees Fahrenheit, and Hemp Wool, which had the average mean of 73.2 degrees Fahrenheit, was the closest to the chosen initial temperature, or room temperature of 78.3 degrees Fahrenheit. Finding the two most efficient materials for the two different critical temperature conditions, heating and cooling, showed that the purpose of the experiment had been successfully completed. Some of the temperatures recorded might seem unusual because the small-scale experiment is a limitation to the temperatures a real home might experience in a real-world application. By observing the data, one generalization that might be made is that the efficient materials might be newer and have some tweaks that adapt to the home environment today. It is also safe to assume that Hemp Wool and Thick Havelock have a higher R-Value. The higher the R-Value, the better efficiency of the insulating material.

Based on the data and conclusions the researcher had developed, a statistical ANOVA test was performed on the means from heating the model homes to find out more about the significant difference between the data. It was discovered that the F-Value of the data set was 29.02084. The F Critical Value was found to be 2.657197. Since the F-Value was greater than the F Critical Value, it was concluded that the test was significant. The null hypothesis was that there is no difference between the means of the eight groups, and the alternative hypothesis was that there was a difference between the means of the eight groups. The P-Value of the data was 7.81668e-08, which is much less than the alpha level, or significance threshold, of 0.05. Due to this, it was safe to conclude that the alternative hypothesis was correct, and there was a statistical difference between the means of the eight groups.

When the ANOVA test had been completed over the heating means, the researcher performed the statistical ANOVA test on the other set of data that was collected, the cooling means. The F-Value of this data set was 17.9976, and the F Critical Value was 2.657197. These values showed that the test was significant because the F-Value was greater than the F Critical Value. The null hypothesis was that there is no difference between the mean of the eight groups, and the alternative hypothesis was that there is a difference between the mean of the eight groups. The P-Value of the data was 1.77e-06, which was less than the significance threshold of 0.05. Therefore, the alternative hypothesis was accepted.

There are a few factors that might have influenced the results. One of these factors included the time the appliance was open between switching model homes with different insulation materials. For example, when the researcher was putting in the fiberglass after heating the oven, they might have left the oven open for a little longer than when putting the cellulose into the oven. This could have allowed some of the oven heat to sneak out, or depending on the room temperature of that day, the temperature from the outside could have changed the oven's inside temperature. This precision might have resulted in inaccuracy, even if it would have been slight.

Another limitation to this experiment that might have caused error was the houses being small-scale models and not the real size of a home. If a real home was implemented in this testing process, it would have cost a lot of money, and taken much more time. However, in the future, the next step to this project might be performing this experiment on a large scale. In the future, the researcher might also consider testing the materials further to find out how well the insulation does with home factors such as sound-blocking and moisture intake of a home.

While looking at the bigger picture, the researcher's performed experiment could be applied to the world. Harmful gasses, such as carbon dioxide and nitrous oxide, are produced as people try to keep their homes cool or heated by producing electricity. Using materials such as Thick Havelock and Hemp Wool, could help decrease the effects of climate change, and potentially reduce one's electricity bills.

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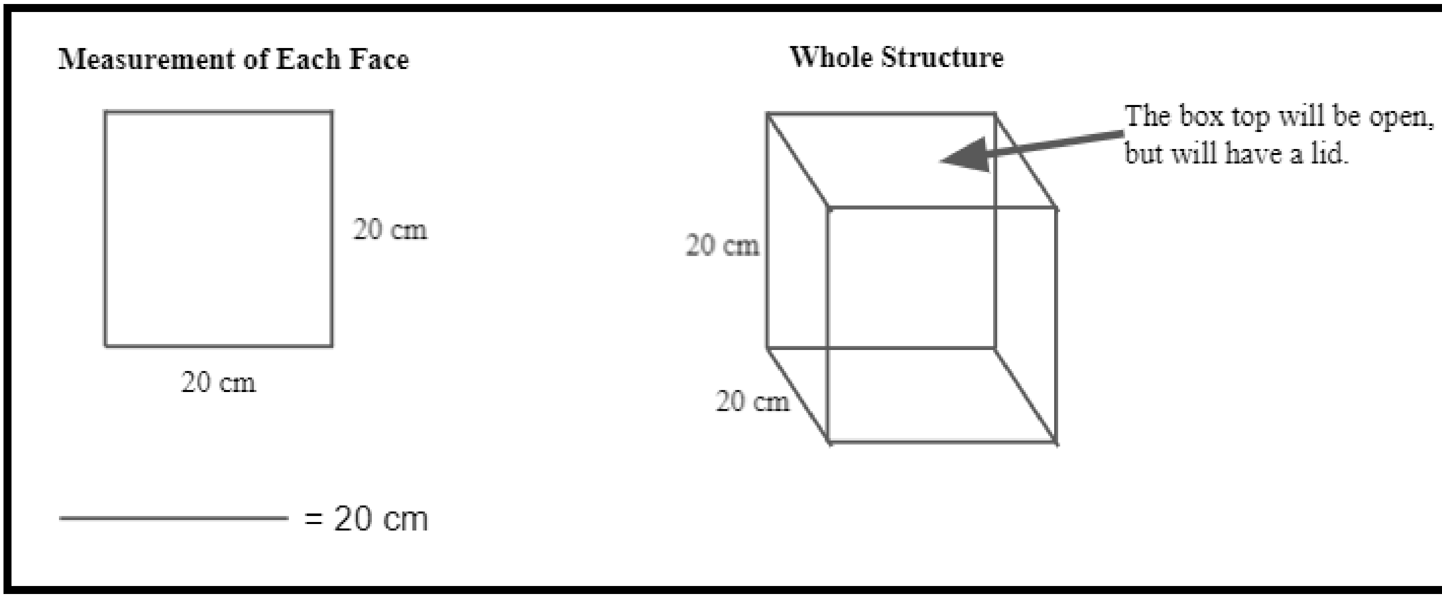
Appendix A

There are many types of insulation, causing the potential for confusion (“Types of insulation,” n.d.). Each of these insulation materials are mainly installed with two methods: batts/roll and blown-in/loose-fill.

Some of the insulation materials installed with the batts/roll method include cotton, straw, sheep, slag, hemp, and mineral rock wool. Cotton fiber insulation is made up of cellulose fibers that are commonly used in clothing materials (“Types of wool insulation,” 2017). Fiber straw is another material made of a natural and renewable resource but is not usually used in humid areas (“Types of insulation,” n.d.). Another common material is natural fiber sheep wool, which is made from the wool of *Ovis aries* and has similar benefits to straw insulation **(“***Wool fiber - natural protein fibers*,” 2019**)**. A similar type of wool is known as slag wool, which is made up of steel production byproducts (“About mineral wool,” n.d.). Hemp wool is a material that is non-intoxicating and can be grown renewable (Greenfield, 2020). Another material is rock wool, which is made from a combination of fibers such as aluminosilicate rock and limestone (“What is rock wool*”*, n.d.).

Loose-fill is the other installation method, commonly used for materials such as fiberglass, cellulose, cementitious, and vermiculite. (The U.S. Department of Energy's Office of EERE, 2010). Fiberglass, the most used insulation material out of all, is made from fine glass fibers. Fiberglass is usually installed using loose-fill insulation, but there are other methods of installation as well (“Types of insulation,” n.d.). Another material is cellulose, used to enclose walls, and made from recycled paper and denim (Ringler, 2021). Cementitious insulation is another type of sealing with a base component of cement, and which is typically installed using spray foam (The U.S. Department of Energy's Office of EERE, 2010). Vermiculite insulation, made up of mica layers with air gaps in between, may also be used (Lipford, 2019).

Appendix B


Measurement of Each Face
20 cm
20 cm
= 20 cm
Whole Structure
The box top will be open, but will have a lid.
20 cm
20 cm