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PHYSICS EXTENDED ESSAY

Investigation of Heat and Sound Insulation

Research Question: How does the heat insulation and sound insulation materials affect each other?

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1. Introduction

1.1 Personal Interest and Explanation of the Experiment

I did my internship in an architecture company. While I was touring the apartments and inspecting them together with my instructor one of the tenants complained that they were disturbed because of the other tenant's noise from a joint wall (partition wall). When we investigated, we found out that the heat insulation made a tunnel effect on the sound insulation in the walls resulting in the dormant state of the sound insulation. This situation reminded me of the insulation problems of the house and I wondered about the relationship between the insulation materials. Then I looked up for the most effective materials in the insulation industry and saw that there are several choices. Having reached this conclusion, I decided to investigate this subject so that I could find the best possible solution for multiple problems in this area. Addressing this issue is critical in architecture and if this issue is not addressed sufficiently, there will be excessive use of materials, work, money, effort, and time.

Because heat and sound are two different things they require different insulation materials to ensure that they fulfill their purposes. Sound insulation protects people from undesired and disturbing sounds, namely noise. It has been observed that noise causes many physiological and psychological disorders, so sound insulation is applied in various places. Heat insulation prevents the loss or unwanted transmissions. If we talk about intended purposes for using insulation, we can divide them into two main groups; structure borne sound and airborne sound. The sources of structure born sounds are for example generator, hydrophore, heater, etc.

1.2 Background Information:

1.2.1 Waves

1.2.1.1 Period

The time it takes for one complete vibration of a vibrating wave source is called period. The period is represented by the symbol T. The SI unit is second(s). Since one full wave is produced for every full vibration period of the wave is equal to the period of the source.

1.2.1.2 Frequency

Vibration of objects moving periodically per unit time is called frequency. Frequency is denoted by the symbol f. SI unit is Hertz (Hz). The frequency of the wave source, is equal to the frequency of periodic waves. Therefore, the frequency depends on the source. The frequency of the wave also does not change unless the setting of the source is changed.

The relation between period and frequency is:

$$T. f = 1$$

The path taken by waves formed in a flexible medium in unit time is called the speed of the wave. The magnitude of the wave's travel speed is indicated by the symbol. The SI unit is m/s. The speed of waves depends on the physical properties of the medium in which they propagate. Speed of the wave does not change unless the media properties change.

Wavelength is the path travelled by the wave in one period. It is based on the concepts of period, frequency and wave propagation speed.

Low-frequency range: 50–200 Hz

Mid-frequency range: 250–1000 Hz.

High-frequency range: 1250–5000 Hz.

1.2.1.3 Sound

Periodic changes of pressure that can be received by the hearing organ of living things is called sound. Sound is a mechanical and longitudinal wave which occurs because of air pressure disturbance due to vibration. Sound is an energy type and there are two conditions that are required for the generation of a sound wave which are a vibratory disturbance and an elastic medium. Sound can propagate in any medium, but not in a vacuum. There is no sound in space. Sounds with frequencies above the human hearing range are called ultrasound. Sounds with frequencies below the range of human hearing are called infrasound. Sound changes according to the temperature and pressure of the environment while passing through the material medium (Solid, Liquid, Gas) in which the substance is located. Historically, there have been six experimentally separable ways in which sound waves have been analyzed. These are pitch, duration, loudness, timbre, sound texture and spatial position

1.2.1.4 Deciel

Decibel (dB) is a logarithmic unit used to measure sound level and express the ratio of two physical values. These compared values can be sound, voltage, electromagnetic wave, intensity, etc. Decibels are related to base 10 logarithms. 1 bel is 10 decibels and it is more common to use decibel instead of bel. The gain or loss of electronic signal and noise is often expressed in decibels. This unit was named in honor of Alexander Graham Bell. The definition of decibel was defined in the United States at the beginning of the 20th century, when Bell Company was making telephone power measurements. Today, this unit is used on a large scale in many fields of science and engineering. These fields can be listed as electronics, acoustics etc.

1.2.2 Heat and Temperature

1.2.2.1 Heat

The energy transferred due to the temperature difference is called heat. Heat flow is from hot substance to cold substance.

Calorie (Cal) or joule (J) are used as heat units.

1.2.2.2 Temperature

Temperature can be defined as a measure of the average kinetic energy of the molecules of a substance. As the temperature of a substance increases, so does the vibrational rate of the molecules. As the temperature decreases, the vibration rate decreases. Use a thermometer to measure the temperature of a substance. Liquid thermometers are designed based on the expansion of liquids, while solid metal thermometers are designed based on the expansion properties of metals. There are three main systems of temperature measurement units most commonly used in thermometers.

Celsius (ºC): It accepts the freezing temperature of water as 0ºC and the boiling temperature of water as 100ºC.

Fahrenheit (ºF): Assumes water freezes at 32ºF and boils at 212ºF.

Kelvin (N): Displays all temperature values as positive. It assumes that water has a freezing temperature of 273 K and a boiling point of 373 K.

1.2.2.3 Heat capacity

Generally, the actual amount of material considered is expressed in calories per degree. In general, the actual amount of material considered is expressed in calories per degree, most commonly one mole (molecular weight in grams). The heat capacity in calories per gram is called specific heat. The calorie definition is based on the specific heat of water, defined as one calorie per degree Celsius.

Heat capacity formula:

$$Q = m \times c \times \Delta T$$

Where;

Q = refers to the heat energy in Joules (J)

m = refers to the mass of the substance in kilogram (kg)

c = refers to the specific heat in joules per kilogram

Δ = refers to the symbol of change

Δt = refers to the change in temperature in kelvins (K)

1.2.3 Insulation materials

When it comes to insulation, the focus is on energy efficiency. The energy efficiency of insulation products is measured by the "R-value" or resistance to heat flow. The higher the R value, the higher the insulating ability.

1.2.3.1 EPS (expanded polystyrene insulation)

EPS is 98% entrapped air and only 2% plastic, making it an efficient insulator using a small amount of raw materials. Expanded polystyrene is versatile and can be molded and cut into a variety of shapes. EPS starts with tiny Styrofoam balls that look like grains of salt. Feed the beads into the mold and use steam and pentane to expand them many times until they completely fill the space. Although usually white, EPS may contain additives such as colorants or insect repellants. (The average R-value for EPS insulation is 3.6 per inch.)

1.2.3.2 Stone Wool

Rock wool is made from basalt, an inorganic raw material. It is made by heating basalt to 1350°C - 1400°C and converting it into fibers. It can be made into cushions, panels, tubes or loose, in a variety of sizes and with different technical properties, with different covering materials depending on the application and where it is used. For thermal insulation, sound insulation, acoustic comfort and fire protection.

1.2.3.3 Corrugated Board

There are mainly four types of corrugated box, single-phase corrugated box, single wall corrugated box, double-wall corrugated box, triple wall corrugated box. Corrugated cardboard is a material consisting of corrugated cardboard and one or two flat linerboards. [1] It is made on a "flute laminator" or "corrugator" for making boxes. Corrugated and linerboard is made from Kraft board, a board material typically over 0.01 inch (0.25 mm) thick. Corrugated cardboard is a material consisting of corrugated cardboard and one or two flat linerboards. [1] It is made on a "flute laminator" or "corrugator" for making boxes. Corrugated and linerboard is made from Kraft board, a board material typically over 0.01 inch (0.25 mm) thick.

1.2.3.4 Glass Wool

Glass wool is an insulating material made of fiberglass called borosilicate glass, which is arranged with a binder into a wool-like texture. It consists of quartz sand, waste glass and fixative.

1.2.3.5 Mineral Wool

Mineral wool is any fibrous material formed by spinning or drawing molten minerals or rock materials such as slag and ceramics. Mineral wool applications include thermal insulation, filtration, sound insulation and hydroponic growing media. Specific mineral wool products are asbestos and slag wool. Humans can be exposed to mineral wool fibers in the workplace through inhalation, skin contact, and eye contact.

Material	Temperature
Stone wool	700–850 °C
Corrugated Board	400-800 °C
Mineral Wool	232-649 °C
Glass wool	230–260 °C

Figure 1: Heat capacity intervals of insulation materials

2 Research Question and Hypothesis

Research question: Is there any significant relationship between heat insulation and sound insulation materials?

Hypothesis: Heat and sound insulation improve the one another.

3 Designing and Conducting the Experiment

3.1Variables

All of the materials I used were waste materials. I used them in order to recycle them. They were donated by the Architecture company ARC Prime. They gave me what they can spare off of their regularly used materials of insulation materials which were on the market on behalf of my want.

3.2 Materials Used in the Experiment

1) TI 84 plus CE-T
2) Sound source
3) Mineral wool

4) Eps

5) Glass wool

6) Corrugated board

7) Paper tape

8) Carpet knife

9) Packing strap

10) Pins

11) Ruler (0-30 cm)

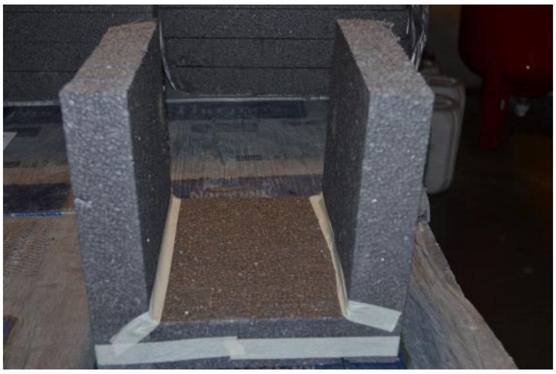
12) Two phones for source of sound and one for measuring it

13) Thermometer

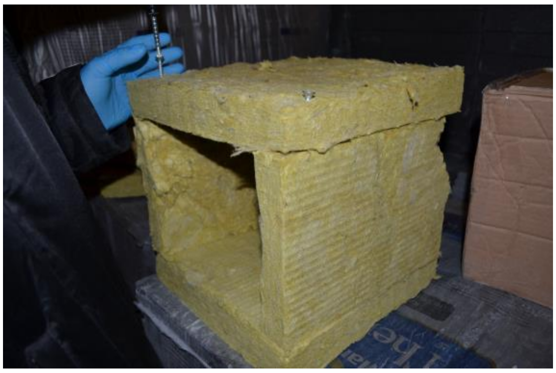
14) “Decibel X “App

Picture 1: Decibel X App’s logo

To investigate the relationship between heat and sound insulation a set-up of a cube module that has six surfaces (measuring as 2(20x20) - 2(20x30) - 2(30x30) each one has 5 cm width except corrugated board) will be constructed from insulation materials. First of all, the listed materials will be put together as individual cubes and experiments shall be done. Then they shall be combined to see which combination is most effective when it comes to both sound and heat insulation methods. The materials and connections between them will be tested by using a tea light candles 10 (±1) grams each for heat experiments and different frequencies between 20Hz - 20.000Hz from recordings on a laptop for sound experiments. The range includes sound and noise like traffic, TV, music, speech and so on, which is audible to humans.

Picture 2&3: Construction of materials

Picture 4&5: Construction of materials

3.3 Steps Followed in Conducting the Experiment

First I moved the materials to the garage where the sound and heat were stable and isolated from the disturbances. I used gloves for protection because rock wool and glass wool has an effect on the skin. They irritate and itch the skin. **(Figure 2)**

Figure 2: Irritated skin

Then I tested them to learn if they are burnable **(Figure 3)** I saw that they do not catch fire but they melt down after some time **(Figure 4)**.

Figure 3: Testing the reactions of the materials to fire

Figure 4: Photo of the melted EPS due to heat

After that I started to gather the pieces together to make the model I designed. I screwed down the rock wool pieces together. I used paper tapes for EPS, packing strap for corrugated board, pins for mineral and glass wool.

3.3.1 Heat Insulation Experiment Steps:

Put the safety equipment first,

Then place the constructed models on a surface,

Carefully lit the tea light candles in the model,

Set the timer,

Read the initial temperature before putting the temperature in the model (be sure that you can read the variables correctly),

Put the temperature in the model, at the same time start the timer,

Read the temperature every 30 seconds and note it down,

Wait for the model and the temperature stabilize and to go back to the initial state and repeat,

Repeat on every ınsulation material.

3.3.2 Sound Insulation Experiment Steps:

Record 2000 Hz, 4000 Hz, 6000 Hz, 8000 Hz, 10000 Hz, 12000 Hz, 14000 Hz, 16000 Hz, 18000 Hz and 20000 Hz sine wave frequencies in one record,

Put the safety equipment,

Then place the constructed models on a surface, Open the “Decibel X” app on 2 phones, one to be placed inside the model and one for out of the model,

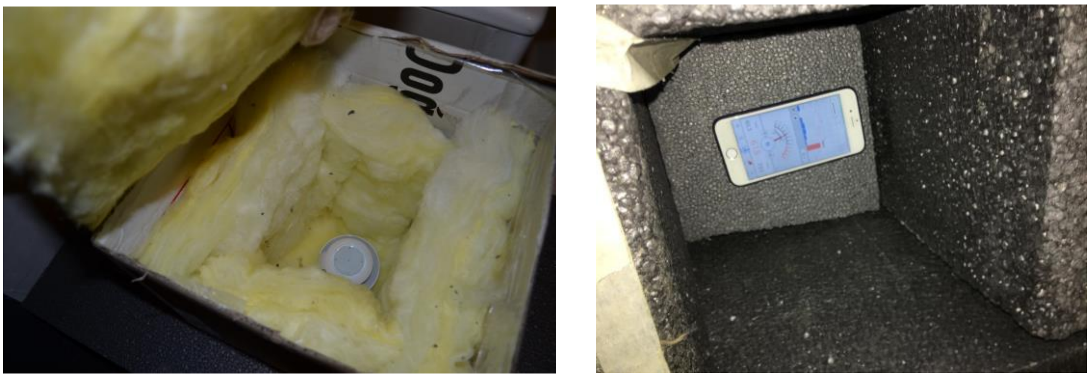
Start the apps at the same time,

Close the constructed cube model,

Then play the recording,

After the recording is finished compare and analyze the values on both assays,

Repeat on every ınsulation material.



Picture 6&7: Testing the app

4 Data Collection

4.1 Data collection of heat experiments

Name Of the Compound		Trial Number and Temperatures (°C) ±1 Throughout Trials									
Glass Wool	Time (s) ± 00.01	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
	00.00	27	27	25	27	27	29	27	27	26	26
	00.30	32	30	30	35	54	38	35	35	32	32
	00.60	38	37	36	43	40	50	45	65	36	38
	01.20	40	42	43	50	46	65	55	65	42	50
	01.50	52	46	48	56	57	61	63	70	56	58
	01.80	59	51	55	63	64	66	68	74	58	64
	02.10	63	60	64	68	70	70	77	81	63	70
	02.40	72	72	73	72	73	74	83	84	70	75
	02.70	79	75	77	77	80	77	88	100	78	78
	03.00	84	82	84	80	85	81	90	104	85	85
	03.30	89	87	89	85	89	83	94	107	89	88

Table 1: Raw Data Table of Glass Wool

Name Of the Compound		Trial Number and Temperatures (°C) ±1 Throughout Trials									
Stone Wool	Time (s) ± 00.01	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
	00.00	26	27	27	29	25	28	26	26	27	27
	00.30	29	30	33	34	30	32	30	30	31	33
	00.60	33	34	39	39	35	36	35	35	35	28
	01.20	37	39	44	44	40	40	39	45	40	42
	01.50	40	45	48	49	45	44	43	50	44	46
	01.80	43	49	52	53	50	48	47	52	47	50
	02.10	45	52	56	57	54	52	50	54	50	53
	02.40	48	55	59	60	58	54	54	58	54	56
	02.70	50	58	62	63	62	58	56	60	57	57
	03.00	51	60	65	66	64	60	59	63	59	62
	03.30	53	62	67	68	67	63	61	65	62	65

Table 3: Raw Data Table of Stone Wool

Name Of the Compound		Trial Number and Temperatures (°C) ±1 Throughout Trials									
Mineral Wool	Time (s) ± 00.01	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
	00.00	27	25	25	27	25	27	28	27	27	28
	00.30	32	31	31	41	27	34	34	35	32	33
	00.60	36	46	37	50	40	47	44	43	35	35
	01.20	42	58	45	60	45	55	55	55	41	38
	01.50	45	71	54	65	52	64	64	66	47	48
	01.80	47	80	59	70	59	68	68	75	57	60
	02.10	50	84	64	76	63	78	73	85	59	68
	02.40	55	85	68	81	71	90	80	93	60	75
	02.70	58	85	73	86	76	91	91	95	65	82
	03.00	61	86	76	90	83	92	100	98	67	87
	03.30	63	88	78	93	88	94	104	100	68	90

Table 3: Raw Data Table of Mineral Wool

Name Of the Compound		Trial Number and Temperatures (°C) ±1 Throughout Trials									
Corrugated Board	Time (s) ± 00.01	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
	00.00	26	26	27	26	28	27	27	27	26	28
	00.30	29	36	32	28	29	30	32	31	30	30
	00.60	32	42	41	30	30	34	34	34	33	33
	01.20	34	45	42	33	34	35	38	36	35	34
	01.50	35	45	42	35	35	36	41	38	38	36
	01.80	37	46	43	37	37	37	42	40	40	38
	02.10	39	46	43	38	38	38	43	41	42	39
	02.40	40	47	44	39	39	39	43	42	43	40
	02.70	41	46	45	40	40	39	44	43	44	42
	03.00	41	46	45	41	41	40	44	44	45	43
	03.30	41	46	46	42	41	41	44	44	45	44

Table 4: Raw Data Table of Corrugated Board

Name Of the Compound		Trial Number and Temperatures (°C) ±1 Throughout Trials									
EPS	Time (s) ± 00.01	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth	Ninth	Tenth
	00.00	26	27	28	25	27	27	28	25	28	27
	00.30	28	29	30	28	29	29	29	27	30	29
	00.60	30	34	32	30	32	32	35	30	32	30
	01.20	31	34	35	32	35	33	36	35	33	32
	01.50	33	35	36	34	37	35	38	35	34	35
	01.80	34	37	38	35	38	38	40	38	36	37
	02.10	35	39	39	38	39	41	42	40	39	39
	02.40	38	40	40	42	43	43	45	43	40	41
	02.70	39	41	41	43	45	45	47	44	42	43
	03.00	43	43	41	44	48	48	499	48	45	46
	03.30	45	49	42	45	53	54	51	55	48	50

Table 5: Raw Data Table of EPS

4.2 Data collection of sound experiments

EPS	Sine Wave Audio Frequency Hz ±1									
Decibel (dB ±0.1)	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
Out of the material	69,3	70,6	63,7	72,8	64,1	65,4	38,6	51,9	33,2	24,4
In the material	64,7	55,8	62,5	41,9	66,5	34,5	35,2	30,3	32,4	16,3
Corrugated Board	Sine Wave Audio Frequency Hz ±1									
Decibel (dB ±0.1)	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
Out of the material	69,3	70,6	63,7	72,8	64,1	65,4	38,6	51,9	33,2	24,4
In the material	67,8	69,1	57,7	61,5	63,3	64,5	36,7	41,2	33,0	20.7
Mineral Wool	Sine Wave Audio Frequency Hz ±1									
Decibel (dB ±0.1)	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
Out of the material	69,3	70,6	63,7	72,8	64,1	65,4	38,6	51,9	33,2	24,4
In the material	54,7	51,8	46,5	53,9	32,9	39,5	21,2	32,3	20,0	10.7

(continues in the other page)

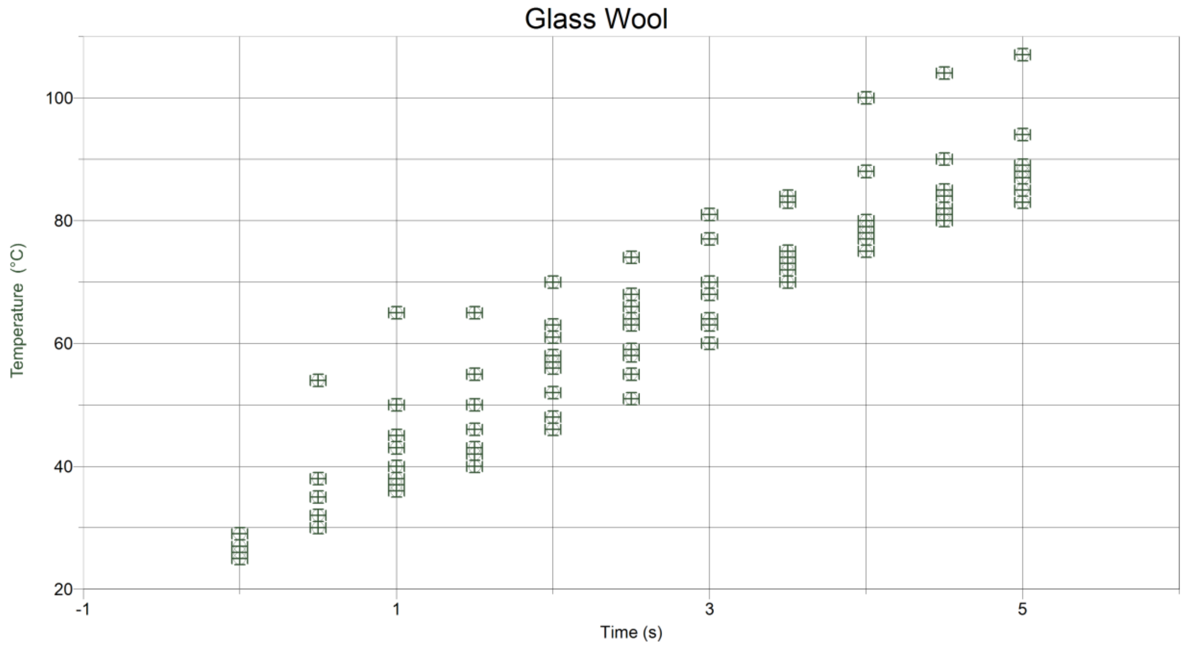
Glass Wool	Sine Wave Audio Frequency Hz ±1									
Decibel (dB ±0.1)	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
Out of the material	69,3	70,6	63,7	72,8	64,1	65,4	38,6	51,9	33,2	24,4
In the material	50,4	52,7	40,5	43,8	32,5	39,3	31,2	32,5	20,9	13.2
Stone Wool	Sine Wave Audio Frequency Hz ±1									
Decibel (dB ±0.1)	2000	4000	6000	8000	10000	12000	14000	16000	18000	20000
Out of the material	69,3	70,6	63,7	72,8	64,1	65,4	38,6	51,9	33,2	24,4
In the material	53,4	51,8	50,7	43,8	38,5	43,3	36,2	44,5	23,9	19.2

Table 6: Raw Data Table of the materials

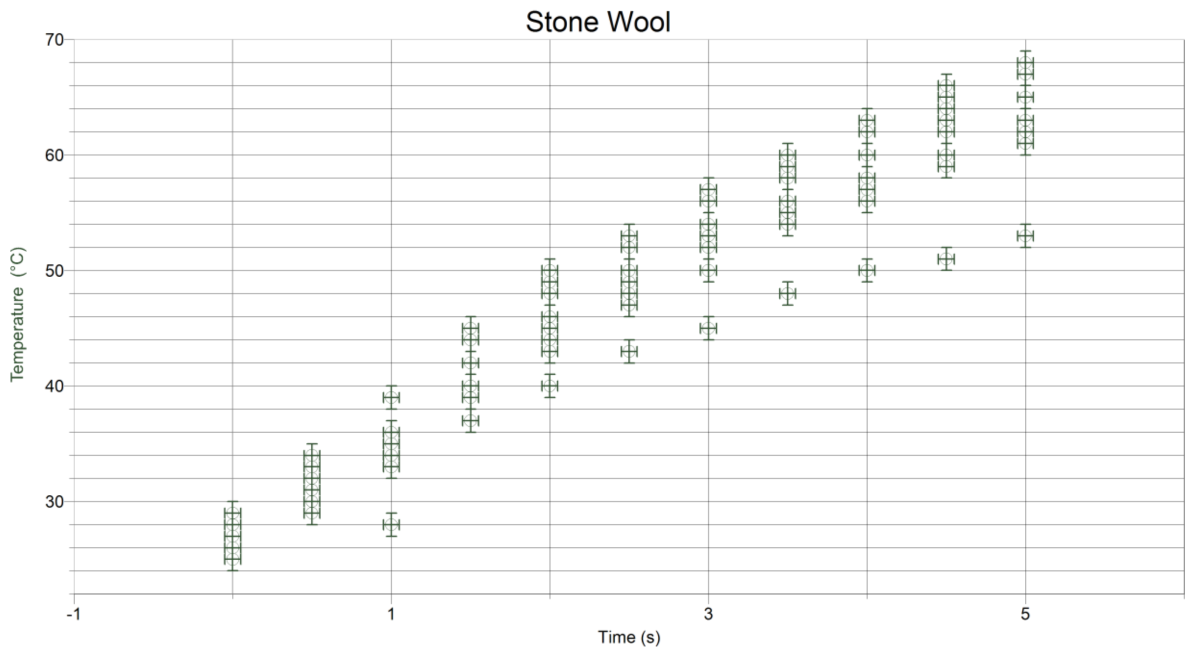
5 Data Analysis

5.1 Heat experiment data analysis

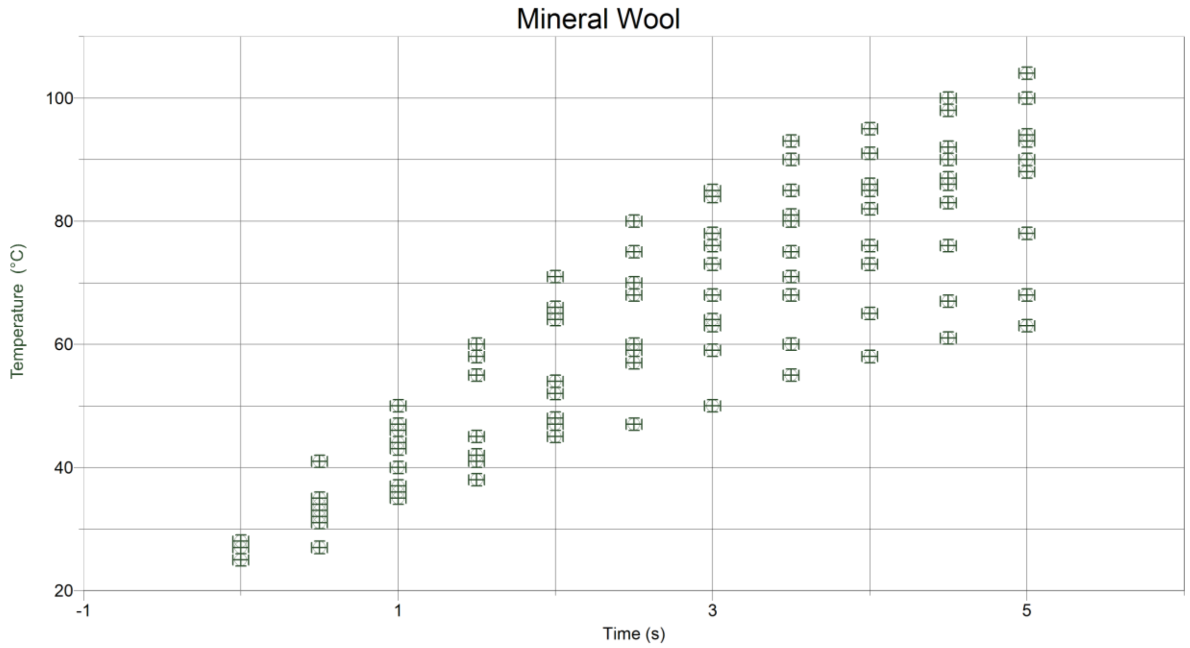
To analyze the data a plot graph is drawn by using Logger Pro 3.0. These graphs show the relationship between time and temperature with different insulants.



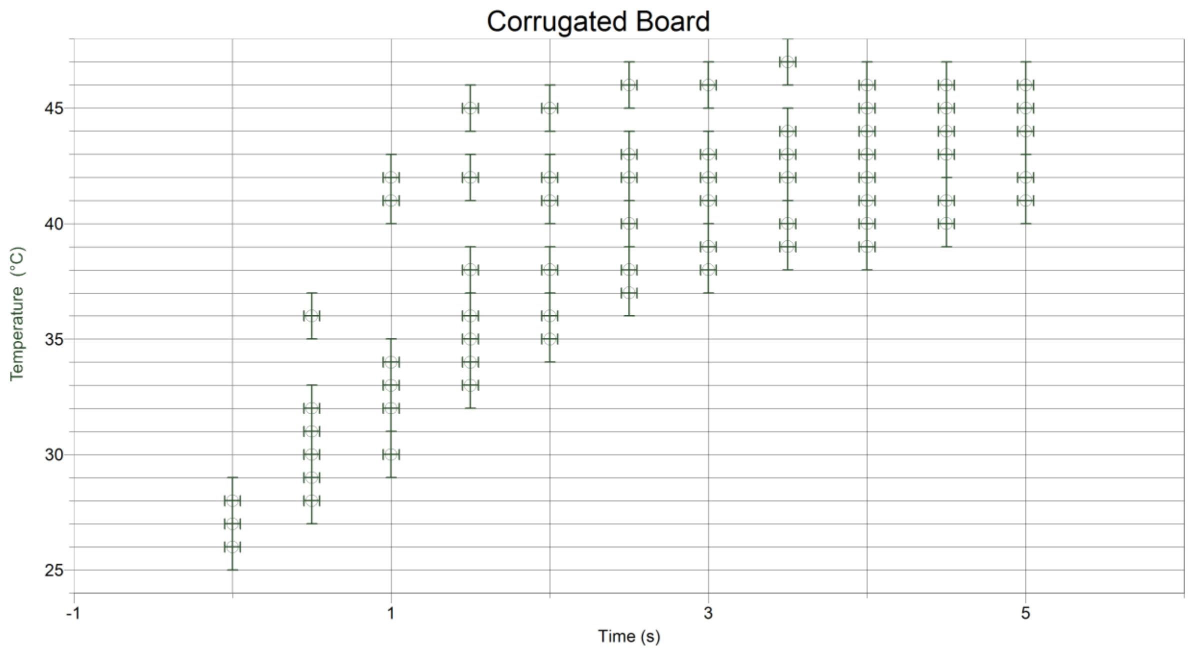
Graph 4: Graph of Glass Wool



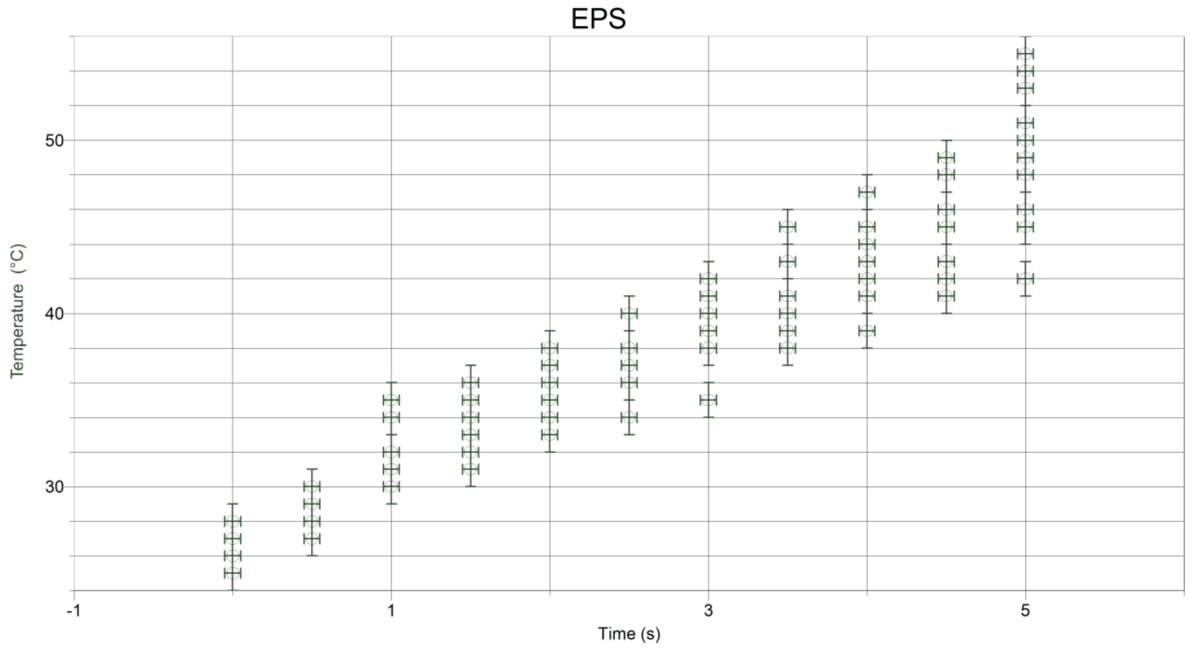
Graph 5: Graph of Stone Wool



Graph 6: Graph of Mineral Wool



Graph 7: Graph of Corrugated Board

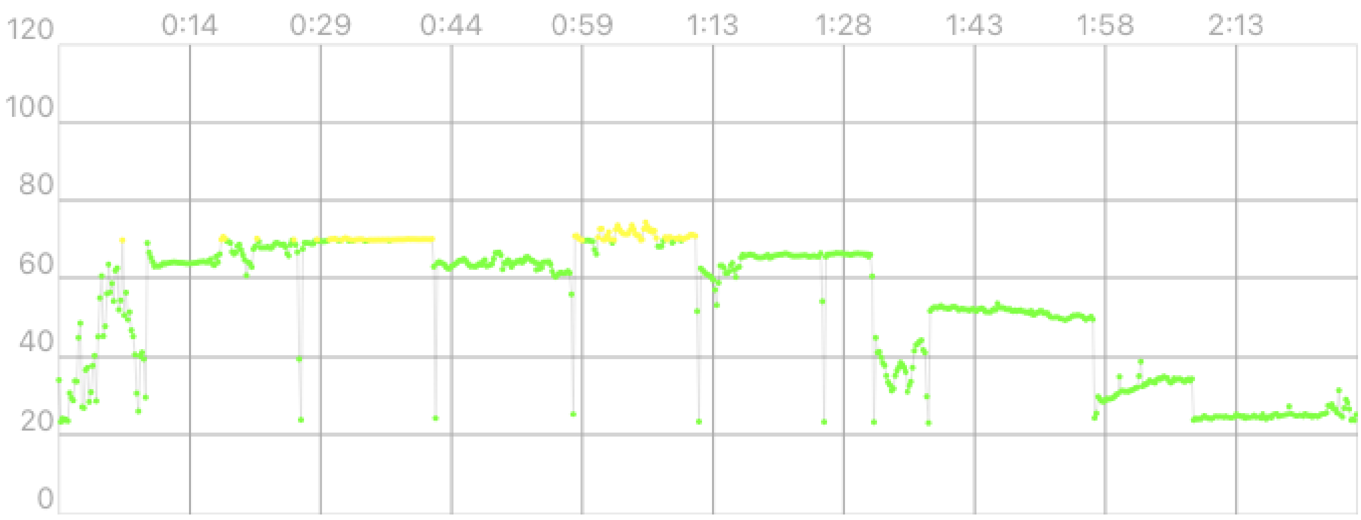


Graph 8: Graph of EPS

5.2 Sound experiments data analysis

EPS (out of the module)

Time(s)

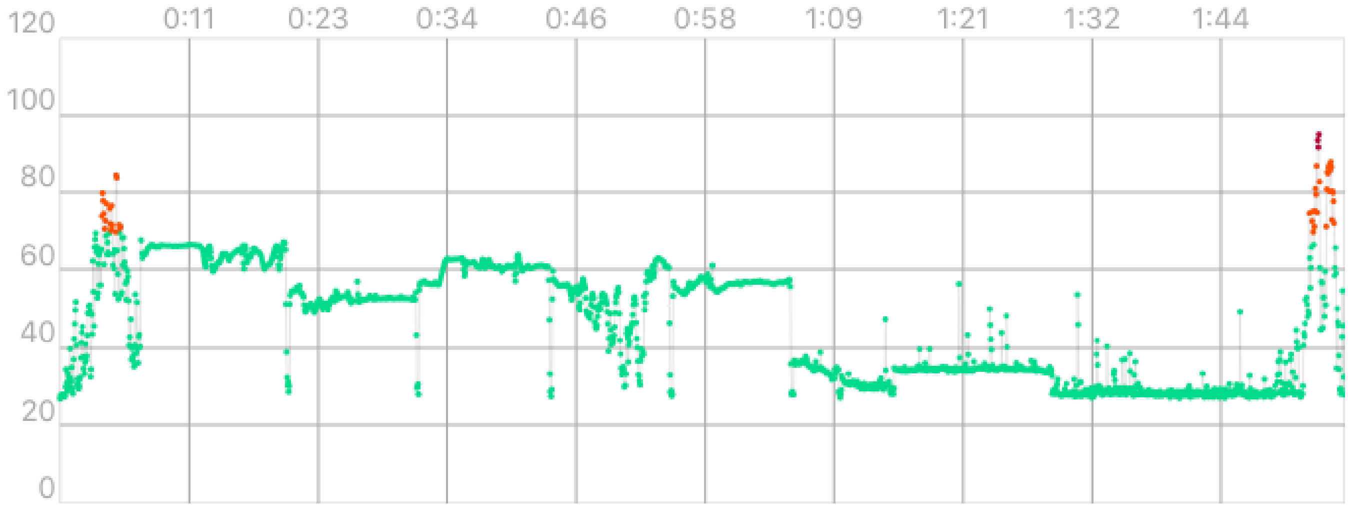


Decibel (dB)

Graph 9: Graph of sound with (in) EPS

EPS (in the module)

Time(s)



Decibel (dB)

Graph 10: Graph of sound with (out) EPS

If we were to consider the results I got, we can say that insulation materials improve both sound and heat insulation in their own requirement areas. However, like mineral and glass wool which are more enriched in terms of air and space are far more effective in sound insulation due to the molecule speed variations in different states.

6 Discussion

If we analyze the results glass wool and stone wool are the most efficient insulation materials when it comes to insulation of heat because of their heat capacities and glass wool and mineral wool are the most efficient insulation materials when it comes to insulation of sound. In conclusion Glass wool is the most efficient one for insulating both heat and sound. This proves my hypothesis being heat and sound insulation materials improve one another.

Heat and sound insulation are most necessary for health and energy saving. There are many benefits of insulation. While the world's energy resources are running out, the human population is increasing so the need for energy for heating and cooling is now much greater. Noise pollution, on the other hand, is one of the stress sources of the new age. We can benefit in the short, medium and long term by making heat and sound insulation to protect both our health and nature. If we use insulation, we can increase the quality of our lives.

Mold and fungus formation in buildings is prevented by heat insulations. Energy efficiency and savings would be increased, the electrical energy consumed for the air conditioner and natural gas used for heating in winter would be decreased. Buildings won't be affected by seasonal changes and the exterior facades against weather conditions lives will be prolonged. Also insulation materials applied to walls, beams and columns increase resistance against earthquakes also provides moisture insulation. It maintains the balance against temperature differences due to seasonal changes and provides comfort. Also it reduces the energy need, reducing the energy used prevents environmental pollution, slows down the increase in the consumption of energy resources.

There are many places that need sound insulations, for example they prevent hearing loss caused by exposure to loud sounds for a long time. They provide protection against noises that may disrupt sleep patterns and better sleep, allow musicians to hear the sound clearer. Reduced concentration is prevented by sound insulation applied to schools therefore efficiency increases. Also insulating the buildings decreases the chance of work accidents caused by lack of concentration in workplaces and soundproofing hospitals are more preferred and better for the healing process of the patient. Similar to that problems such as headache, nausea, mental drowsiness, heart diseases and hormonal changes caused by noise pollution and negatively affecting daily life is reduced by insulation too.

Theoretical Proof:

Equation for speed of sound in dry air:

$$c_{\text{air}} = (331.3 + 0.606 \cdot \theta) \quad \text{m/s},$$

Where:

θ is temperature in degrees (°C)

Equation for speed of sound in three-dimensional solids:

$$c_{\text{solid,p}} = \sqrt{\frac{K + \frac{4}{3}G}{\rho}} = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}},$$

K is the bulk modulus of the elastic materials;

G is the shear modulus of the elastic materials;

E is the Young's modulus;

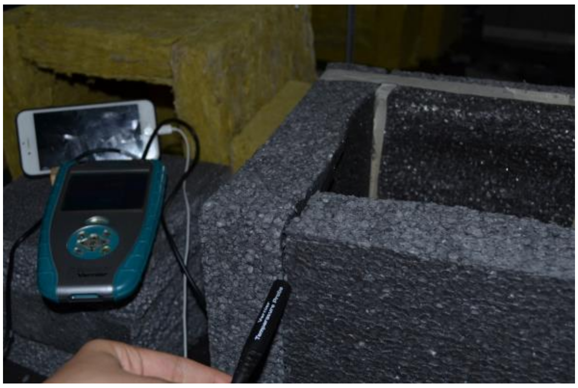
ρ is the density;

ν is Poisson's ratio.

In light of these equations we can say that speed of sound in solids is greater than speed of sound in gases due to the distance between molecules.

7 Conclusion and Evaluation

I didn’t wait enough for the model to cool down and the candles were inside while the probe was cooling down. I used 4 little even candles but I did not light up a brand new tea light candle every trial or when I pass down to the other material. Also I did not between the trials so after the first experiment the models degree was already begun to heat up. As a result of these we can say that there is systematic error which I caused. Also I used timer but because I started and stopped it the results didn’t come out precisely, this is human error. I suggest the people who are going to do this experiment that they should make bigger cubes so that there will be more oxygen to use and the surfaces won’t be that close to the fire thereby the materials wont melt easily and quickly. Despite this there should be a fire-extinguisher nearby to be used in case of emergency. Also they should use more protection such as googles, a smock, longer gloves which covers further than ankles. Before I used the thermometer I used Vernier but the results I got did not satisfied me and the error range was broad **(Picture 9 & 10)** and before that I tried to use one of the alarm clocks but their degrees were not sensitive enough and there were some visible damages. **(Picture 11 & 12)**



Picture 9 & 10: Vernier Lab Quest in the experiment

Picture 11& 12: Damaged alarm clock thermometers due to heat

8 Further Research

To examine the topic furthermore there are things to improve in order to achieve better and more accurate results. To enhance the experiment a system that sets the timer at the exact time as we put the thermometer can be placed and the two phones can be connected together and programmed to start the app at the same time too. Stabilizing the room temperature can also help us get better results in both heat and sound experiments and repeating the experiments in different seasons of the year in different climates. Also to minimize the noise which can cause errors, the experiments can be practiced in a soundproofed area.

Still, we can say that both sound and heat insulation act their roles in their own demand areas, if we were to consider the results I got. Still, like mineral and glass hair which are more fortified in terms of air and space are far more effective in sound insulation due to the patch speed variations in different states. This proves my thesis being heat and sound insulation ameliorates one another.

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