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A Comparative Performance Analysis of Different Insulation Materials Installed in a Residential Building of a Cold Region in Pakistan

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Abstract: Globally, the building sector consumes approximately 60% of the total energy usage, while the energy consumption of residential buildings lies between 20% to 40%. The majority of this energy is operational energy, which comes mainly from the heating and cooling of houses. Innovative and cost-effective insulation materials have the potential to reduce the operational energy requirements and can therefore make the buildings more energy efficient. In this study, three commonly available insulation materials were experimentally evaluated for a case study of residential buildings, located in a cold region of Pakistan. Glass wool, extruded polystyrene, and polyethylene were used, as insulation materials, for monitoring the case study building performance. Thermal data were collected for 21 days in the year 2019 using a Testo Saveries System and were then used for analyzing the thermal performance of each of the three types of insulation materials. Other relevant data including the cost of insulation materials, thickness, ease of application, design life, and fire resistance of the selected insulation materials were obtained for broader (based on the scorecard) analysis based on a multi-weighted decision model. It was concluded that Polyethylene was the most economical insulation material amongst the others, which also showed the best thermal performance. Polyethylene was also found to be the best insulation material for the case study building based on a multi-weighted decision model and, hence, is recommended for application in buildings around cold regions of Pakistan.

Keywords: energy efficiency; operational energy; residential buildings; insulation materials; building envelope; Pakistan

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1. Introduction

The energy and environmental crisis is a multi-aspect issue, which needs action in different layers of the world community. The utilization of energy-efficient techniques and green architectural features is the real need for the time the remedy this complex matter and enhance environmental and socio-economic benefits [1,2]. Environmentally, it helps to conserve natural resources and minimize issues regarding pollution and destruction of the environment. In terms of economics, the cost of resources should be reduced as a means of conservation. Socially green buildings are architecturally appealing, with no negative effect on the built environment and infrastructure [3]. There are various innovative ways to improve the energy efficiency of buildings [4]. However, one approach in the practice of improving the energy efficiency of buildings is using thick layers of insulation to minimize the energy leak and waste [5], but the issue is, in many scenarios of renovation and new building design, space efficiency is a very important consideration along with thermal performance and cost-efficiency. To achieve space efficiency, we need to develop appropriate insulation materials with less thickness and comparative thermal performance. Insulation materials are used within building assembly as roofs, walls, and floors vary by source of manufacturing [6] and country context [7]. Using innovative material in residential building construction has the potential to enhance affordability and sustainability [8].

Pakistan is facing energy crisis for the last couple of years [9], which is slowing down its economic development of Pakistan. The building sector consumes almost 30% of the total energy in Pakistan and it is continuously raising annually at the rate of 4.7% in residential and 2.5% in commercial buildings. The extreme weather conditions of Pakistan's coldest regions make it important for insulating houses in those regions for thermal comfort [10]. Humans strive to keep their bodies in a comfortable environment considering the outdoor temperature. A house being insulated (maintaining suitable temperature in summers and winters) is the prime concern of all the occupants. In total, 60 to 80% of the total energy cost is consumed for the heating and cooling of houses in Pakistan, where per capita annual average energy consumption is around 475 KWh [11]. The main energy utilization is for heating and cooling purposed and should be prioritized while designing local buildings [12].

For improvement of thermal comfort at high altitudes, careful selection of insulation material with proper insulation rating is necessary [13]. Residents of this region have the only option to use 3–5 tons of wood per winter season for hose heating since most of the residents are economically challenged and have rare access to electricity or gas supplies. However, for many buildings in northern areas of Pakistan, 60–70% of operational energy is lost through the walls and roof. Occupants pay 13th times their earnings on fuel for heating their house [14]. In addition, most of the residents, primarily ladies, kids, and seniors usually fall sick due to continuous exposure to smoke during winters. The demand for wood accelerates deforestation and harms the environment in a bigger perspective. Therefore, there is a crucial need of defining ways to minimize heat loss through walls and roofs, which may be achieved through efficient insulating materials [15].

Thermal insulation is essential for the thermal performance of residential buildings in cold regions, of developing countries, to attain a comfortable room temperature with minimum carbon emission. Hence, proper selection and treatment of insulation material create significant differences specifically in roofs and walls shaping building envelop [16], and similarly, selection of structural system [17]. Non-natural thermal insulation materials are equivalently more efficient than insulation produced by natural sources [18]. However, there are constraints associated with availability and processing cost, which push the specifiers to investigate the performance of insulation materials used for non-structural building elements. Further, the selection of the insulation material primarily depends on the technical aspects such as thermal sensitivity, fire resistance and carbon emission, but the commercialization and unconventional source of insulation also gain significance [19] and efficient energy conversation [20]. In earlier research, studies tested various thermal insulation materials to evaluate their conformity with cold climate conditions and contextualized them in a country perspective for availability and least cost [21]. However, limited research has been conducted to evaluate the performance of locally available unconventional insulation materials in the cold region of Pakistan.

Murree is a city in the northern region of Pakistan where every year, more than 1 million families live at about 6.17 °C mean temperature for over 5 months [22], refer to Figure 1 for annual temperature and precipitation data. Houses in this high-altitude region are conventionally made of stones, while some modern buildings are of concrete blocks without any insulation [23]. The main source of energy comes from non-renewable sources, which are hazardous to the environment, therefore needing to achieve thermal comfort by other means. A holistic energy-efficient building design approach has the potential to reduce the size of mechanical systems compensating for the additional cost of energy requirements [24]. Specifically, this study investigates the effectiveness of three different types of insulation material applied in different rooms of a house building to determine the most favorable material for residential buildings in the cold regions of Pakistan.

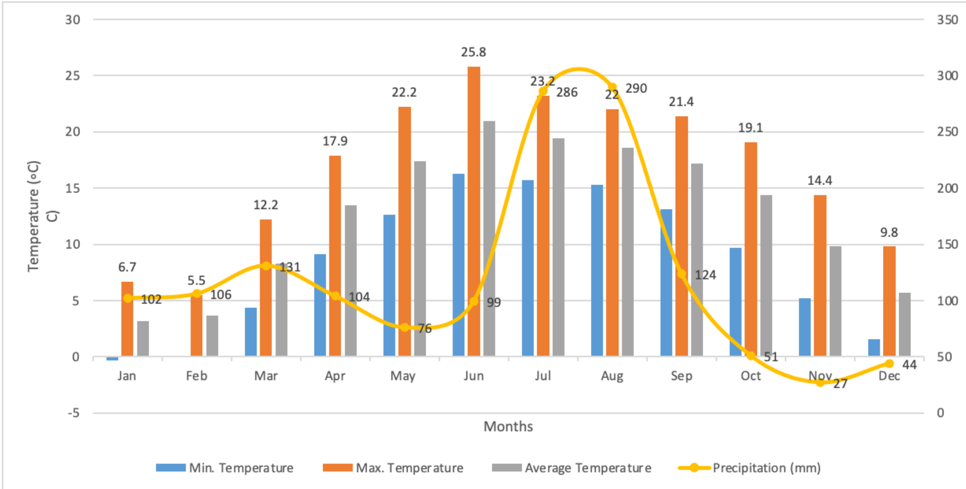

Figure 1. Annual temperature and precipitation data for Murree, Pakistan, recorded for the year 2018.

Glass wool is an insulating material made from fibers of glass arranged using a binder into a texture similar to wool [25]. The fibers in glass wool help to trap the air between the glass wool and can therefore stop the airflow. Glass wool is available in different forms, in rolls, sheets, and preformed pipe sections. Its thermal conductivity ranges from 0.031–0.042 W/mK. The density of glass wool varies from 10 to 80 kg/m^3 with a service temperature range of -200 °C to 450 °C [26]. Polyethylene foams are closed-cell insulation materials that are being developed to enhance the thermal performance of walls and roofs. It is generally used for pipe insulation for frost protection and to conserve energy. The density of polyethylene foams ranges from 30–60 kg/m^3 and the thickness varies from 6–32 mm. The thermal conductivity of polyethylene foams varies from 0.033 to 0.045 W/mK with service temperatures ranging from -50 °C to 105 °C [20]. Polystyrene is available in the global market in two different forms, either expanded or extruded. Its density varies from 15–30 kg/m^3 and thickness can range anywhere between 5 to 610 mm with thermal conductivity of 0.033 to 0.038 W/mK. The service temperature of polystyrene ranges from -150 °C to 80 °C and the water vapor transmission rate is 25 µgm/Nh [20].

The Testo Saveris data monitoring system is ideally suited for temperature monitoring and temperature control in most of the applications. It provides fully automatic measurement of temperature and humidity values. The measurement data transfer takes place by wireless and/or ethernet connection to a Base station. If limiting values are exceeded, several alarm options such as SMS/e-mail alarm or alarm relay are available. Remote alarms can also be triggered even when the system is not connected to a running computer. In addition to this, transmitters of all measurement parameters with standard current/voltage interfaces can be integrated into the Testo Saveris system [27]. All recorded data are centrally stored in the software. At the same time, the Testo Saveris software also allows a comprehensive analysis and evaluation of the recorded data [28].

2. Materials and Research Methodology

In this study, experimental research evaluates the thermal performance of insulation materials for the cold climate, which are generally used in a hot climate in Pakistan. A case study building in the northern region of Pakistan (a city called Murree, most populous hill station), was selected to check the thermal performance of different insulation materials. The three most common and commercially available insulation materials in that region of Pakistan, i.e., glass wool, polyethylene, and extruded polystyrene were installed on the walls and inner side of the roof in three similar rooms of a single-story study building, see Figure 2.

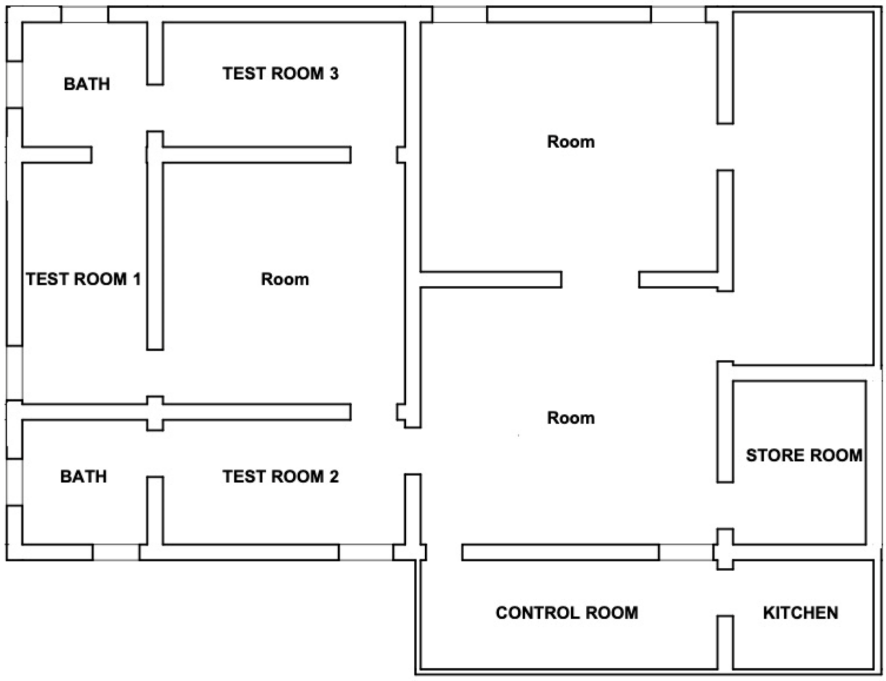

Figure 2. Floor plan of the case study building.

The device that was used for temperature monitoring is called the "Testo Saveries System" made in Germany has several wireless temperature probes with display screens and a router. For the subject study, one probe was installed in each test room on the exterior facing wall at 2.13 m level to measure indoor temperature. Probe specifications are given below.

The data of temperature measurement was taken in 4 test rooms from 22 January 2019 to 11 February 2019 on 24 hourly bases, and then the average daily temperature of three insulation test rooms was taken for comparison with the control room and outdoor temperature data to evaluate the significance of insulation materials relative to their cost and respective thickness in the subject study.

The most commonly used methods are the average method, the method for correction of storage effects, and the linear regression method. They all are based on stationary boundary conditions. These methods use averaged data as an approximation of measured data under stationary conditions [29]. The major disadvantages of these methods are long measurement periods and the impact of small temperature differences and heat flow compared to thermal storage in the wall. Gaspar et al. [30] found that at optimal environmental conditions, the difference between measured temperature values is ±5% for the average method.

In addition, a multi-weighted decision approach was used to arrive at a final judgment on the best material assembly for residential constructions in Pakistan's northern regions. The elements were chosen based on the cost-effectiveness, thermal performance, thermal conductivity, space efficiency, ease of application, environmental impact, market availability, and nature conservation for the evaluation of the scorecard after a thorough assessment of the results. The prediction data was acquired through interviews with 20 people from the Murree community, field experts (Architects) from the same region, and the technical personnel from all three different insulating material businesses to assign weightage to each part of the scorecard.

2.1. Selection of the Case Study Building

For the research, the Murree region in Pakistan was selected because of the high altitude of 2291 m above sea level. The climatic data of the Murree region for the year 2018 was taken as the benchmark for the research. According to the climatic data, the annual temperature of the Murree region ranges from 3 °C to 19 °C. The minimum temperature recorded in the year 2018 was 3.2 °C in January. While the maximum temperature was recorded as 19.6 °C in July as mentioned in Table 1. The month with the fewest daily hours of sunshine in Murree is January with an average of 8.43 h of sunshine per day. Around 3491.84 h of sunshine are counted in Murree throughout the year. On average, there are around 114.77 h of sunshine per month.

Table 1. Zonewise probe specification.

Description	Zones	Serial No.	Temp. Range
Probe 1	1	01547942	−20 °C up to +50 °C
Probe 2	4	01550140	−20 °C upto +50 °C
Probe 3	3	01652256	−20 °C up to +50 °C
Probe 4	2	01607756	−20 °C up to +50 °C

A single-story heritage farmhouse (in Pakistan, locally known as Dar House), located near Hamza CNG, sunny Bank, Cart Road, Murree region of Pakistan with the corrugated roof was selected for the case study building, which had three different insulation materials installed in three different rooms of the building. This house has 4 rooms of equal size. The selected house was made in the stone finish with a pitched roof as shown in Figure 3.

Figure 3. Photograph of the case study building (Stone finished, single-story with pitched roof).

2.2. Test Room Specification

Three different materials were installed in three separate rooms. All three rooms had an equal size of 4.72 m × 2.44 m × 3.05 m, with one wall exposed to the outside environment, and the other three walls were sandwiched irrespective of the direction of the walls. The 4th room was monitored as an untreated conventional room, i.e., the control room as shown in Figure 2. The walls were 229 mm thick and made of stone masonry cast and plastered with lime and mud mortar and whitewash finish. The exposed wall dimensions in each test room were 4.98 m × 2.64 m with a window of size 1.07 m × 1.42 m. The roof of the building had a 4 mm thick corrugated sheet supported by wooden battens and beams. Orientation is not considered as a parameter in the subject study, which is a limitation, but was avoidable due to no sun exposure in the building during the study time duration.

During the data collection from the case study building, the house was fully covered by snow, as shown Figure 4.

Figure 4. Exterior Views of the case study building with snow coverage.

2.3. Insulated Materials and Data Collection

Three different insulation materials were selected and installed in three different rooms of the case study building, which are commercially available in the local market, and can be easily installed and manageable as per the following detail mentioned in Table 2. The insulation materials were selected with their minimum effective thickness as per market availability. Glass wool, having a 25 mm thickness, 24 kg/m^3 of density, and 0.032 W/m·K of thermal conductivity was applied under the corrugated sheet and on one of the exposed walls of the case study building [31]. Extruded polystyrene, having 25 mm thickness with a density of 35 kg/m^3, and having a thermal conductivity of 0.026 W/m·K [32], was applied under the corrugated sheet as per the ASTM C518 [33] on one of the exposed walls in test room 2. Polyethylene rolls of 12.5 mm thickness, having color with aluminum foil (28 kg/m^3 density (100% closed cell) and having a thermal conductivity of 0.0298 W/m·K [34] were installed as per the ASTM C177 [35] standard, by using an adhesive under the corrugated roof and on one of the exposed walls in the test room 1. No insulation was applied in room 4 of the case study building as shown in Table 2.

Table 2. Type and details of insulation materials.

Sr. No.	Material	Thickness (mm)	Thermal Conductivity W/m·K	Specific Heat (kJ/kg K)	Room Arrangement
1	Glass Wool Roll	25 mm	0.032	0.9–1.0	Test Room-1
2	Extruded Polystyrene Sheet	25 mm	0.026	1.45–1.7	Test Room-2
3	Polyethylene Roll	12.5 mm	0.0298	2.3	Test Room-3
4	No Insulation (Control room)	Not applicable	-	-	Test Room-4

Glass wool and extruded polystyrene were applied in sandwiched form with the help of a wire mesh enclosed in the wooden frame. However, polyethylene rolls were applied by using elephant bond as adhesive under the corrugated sheets and on one of the exposed walls as shown in Figure 5.

(a) Test Room 1 (Glass Wool Roll) (b) Test Room 2 (Polystyrene Sheet) (c) Test Room 3 (Polyethylene Roll)

Figure 5. Interior pictures of test rooms with insulations being applied.

2.4. Data Collection and Analysis

Twenty-one days of temperature variation data were recorded. Thermal probes were used for recording all measurement data, which were then integrated into the Testo Savers system and then transferred to the computer system via the router. Tables and figures were developed based on interpretation and comparative analysis of recorded data. Daily outdoor temperature was noted from the online weather report of Murree to compare with indoor temperature. The indoor ambient temperature of the control room was also measured for comparison with test rooms.

3. Results and Discussion

The data collected in this study includes two parallel steps. In the first step, the temperature data was collected from the onsite sensors, and then were analyzed by Testo Saveris System. Furthermore, the temperature data obtained from the three test rooms were compared with the data obtained from the control room with no insulation, see Figure 6. While the focus of the first series of analyses was on the thermal efficiency of different insulation materials, the focus on the second step was wider and based on a multi-weighted decision model. At this step, the data regarding the cost of insulation materials, ease of application, availability, fire resistance, and useful life, were captured, and then the results were used to check on the best suitable and efficient material.

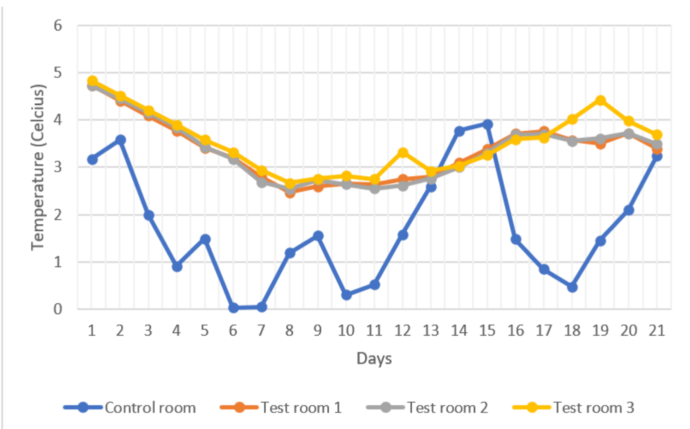

Figure 6. Comparison of temperature data of control room and test rooms.

3.1. Comparative Thermal Analysis of Control and Test Rooms

Three insulation materials were compared with test room temperature data individually and then these were compared with each other to evaluate the better insulation material for the northern areas of Pakistan.

As shown in Figure 6, for test room 1 the temperature ranges from −2.43 °C to 3.48 °C in a single day with a variation of more than 6 °C within 24 h in the control room without any insulation. The measured data shows that on the 17th day of experimentation minimum thermal variation was recorded with a minimum of 0.6 °C and a maximum of 1.10 °C, i.e., variation of only 1.16 °C. Therefore, the recorded data reflects that there are multiple levels of variations in the temperature of the control room based on variations in outdoor temperature. In comparison to the control room, temperature data of the test room shows a maximum variation of 1.29 °C and a minimum variation of 0.05 °C during the 24 h, which clearly shows that test room 1 with glass wool insulation shows quite favorable results in comparison to the control room with no insulation being applied.

Figure 6 shows the thermal data comparison between the control room with no insulation and test room 2 with extruded polystyrene insulation. The data shows that the average temperature of the control room varies from 0.03 °C up to 3.25 °C on the last day of experimentation. However, in the case of the test room 2, the temperature variation ranges from a minimum 2.28 °C on the 8th day of experimentation and maximum goes up to 6.27 °C for the only day, otherwise average daily internal temperature variation is a maximum 1–2 °C.

The temperature in the control room without any insulation ranges from −2.43 °C to 3.48 °C in a single day, with a variation of more than 6 °C within 24 h, as shown in Figure 6. The measured data shows that on the 17th day of the experiment, the lowest thermal change was just 1.16 °C, with a minimum of 0.6 °C and a maximum of 1.10 °C. As a result of the collected data, there are numerous levels of temperature differences in the control room as a result of changes in outdoor temperature. While in comparison to the control room, the temperature variations in test room 3 are comparatively very low with a minimum of 2.92–2.94 °C on the 13th day of experimentation. In test room 3, the temperature variation was minimum, i.e., 1–1.5 °C during all days of experimentation.

After comparing three test room results with the control room data, a comparative analysis of the thermal performance of all three test rooms and the control room was conducted. The performance of material assembly 3, which is a polyethylene roll with aluminum foil, showed slightly better results in comparison to other test room materials, as shown in Table 3, but in general, all test rooms had quite better results in comparison to the control room, but comparative performance to each other, which shows their equivalence in thermal performance.

The data from Table 3 shows the mean temperature of the control room is 1.7 °C, while the average 21-days temperature in Test Room 1 and Test Room 2 was two times higher than in the control room, being 3.4 °C. During the same period, the average room temperature at the test room, which was insulated with polyethylene roll with aluminum foil, was the highest and recorded at a temperature of 3.5 °C.

To analyze the comparison between the thermal performance of three test room insulation materials, paired comparison test was applied in statistical analysis software SPSS and it was observed that a significant difference in thermal performance of the control room and individually all three insulated rooms were there, but the performance of these insulation materials was equivalent to each other. This analysis shows that these three insulation materials have similar thermal performance in cold climatic conditions of the test building region, as shown in Figure 7. The results of the independent sample Kruskal–Wallis test also reflect the same.

Table 3. Average comparative analysis of 21-days monitoring.

Sl. No.	Dates of Data Collection	Outdoor Temp (°C)	Ambient Indoor Temp of the Control Room (°C)	Avg. Indoor Temp in Test Room 1 (°C)	Avg. Indoor Temp in Test Room 2 (°C)	Avg. Indoor Temp in Test Room 3 (°C)
1	22 January 2019	3	3.17	4.73	4.72	4.83
2	23 January 2019	3.5	3.58	4.41	4.45	4.52
3	24 January 2019	2	2.00	4.09	4.15	4.21
4	25 January 2019	1	0.91	3.77	3.85	3.90
5	26 January 2019	1	1.49	3.41	3.43	3.58
6	27 January 2019	−1	0.03	3.19	3.17	3.32
7	28 January 2019	−3	0.05	2.79	2.69	2.94
8	29 January 2019	−3.5	1.19	2.47	2.54	2.67
9	30 January 2019	0	1.55	2.59	2.73	2.76
10	31 January 2019	0	0.30	2.66	2.64	2.82
11	01 February 2019	−1	0.52	2.64	2.55	2.75
12	02 February 2019	0	1.58	2.75	2.61	3.32
13	03 February 2019	1	2.60	2.79	2.76	2.92
14	04 February 2019	−2	3.77	3.09	3.00	3.03
15	05 February 2019	0	3.92	3.38	3.30	3.26
16	06 February 2019	1	1.48	3.71	3.69	3.59
17	07 February 2019	−1	0.85	3.76	3.70	3.63
18	08 February 2019	0	0.48	3.57	3.55	4.02
19	09 February 2019	1	1.45	3.50	3.61	4.42
20	10 February 2019	1.5	2.10	3.72	3.72	3.98
21	11 February 2019	2.5	3.25	3.39	3.49	3.69

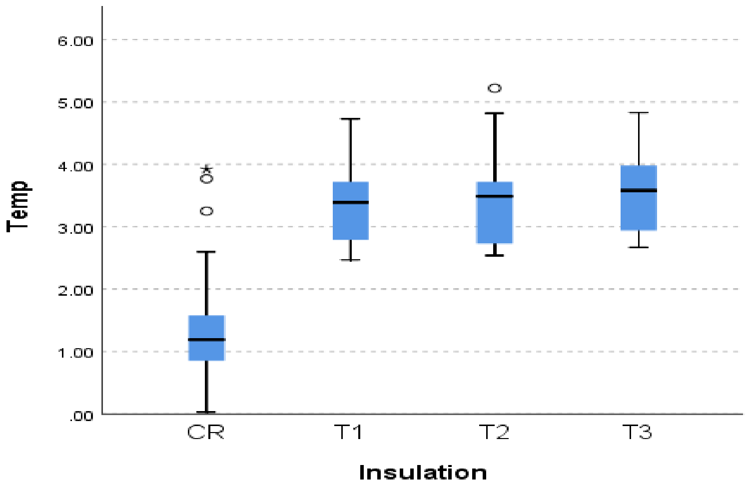

Figure 7. Independent sample Kruskal–Wallis test.

3.2. Comparative Analysis of Average Measured Temperature, Cost & Thickness of Experimented Insulation Materials

Comparative analysis of average thermal performance reflects similar behaviors in case of glass wool and the extruded polystyrene, i.e., 3.35 °C, and better performance in the case of polyethylene, i.e., 3.53 °C, as shown in Table 4. Cost analysis of three different types of insulation materials was conducted based on the market survey, which was facilitated by the information provided by different suppliers of the insulation materials and from the technical brochures of those materials. The results showed that material assembly III, polyethylene roll with aluminum foil was the most cost-effective material when compared with the other two types of insulation materials as shown in Table 4. In terms of material thickness, polyethylene is a preferable material in comparison to polystyrene and glass wool due to half of the thickness ensuring space efficiency.

Table 4. Comparative analysis of average measured temperature, cost and thickness of experimented insulation materials.

Sr. No.	Name of Insulation Material	Average Measured Temperature (°C)	Cost in USD/m^2	Thickness in mm
1	Glass Wool roll	3.34	0.03	25
2	Extruded Polystyrene sheet	3.35	0.05	25
3	Polyethylene roll	3.53	0.01	12.5

Table 4 shows that the polyethylene roll has the best thermal efficiency, which is also the cheapest option. Using glass wool roll and polystyrene sheets cost approximately three times and five times more than the cost of polyethylene roll, respectively.

3.3. Comparative Analysis of Other Parameters for Three Different Types of Insulation Materials

While monitoring the thermal performance of the case study building, it was found that the thickness and density of different insulation materials have a significant influence. Glass wool and extruded polystyrene sheets were 25 mm thick, while the thickness of polyethylene roll was only 12.5 mm. Therefore, polyethylene was found to be a preferable option. In terms of fire resistance, all three different insulation materials belong to class A, as shown in Table 5.

Table 5. Comparative analysis of different parameters for three different types of insulation materials, extracted from [36].

Sr. No.	Description	Glass Wool	Extruded Polystyrene	Polyethylene
1	Cost-Effectiveness	Medium	Low	High
2	Thermal performance (experimentation)	Good	Good	Better
3	Thermal Conductivity	0.032 W/m·K	0.026 W/m·K ASTM C518	0.0298 W/m·K ASTM C177
4	Thickness	25 mm	25 mm	12.5 mm
5	Ease of application	Low	Medium	High
6	Impact on Environmental	4.5 Quite safe environmentally, some concern that fibers may be carcinogenic	5.25 Produced with HCFC 142b which depletes stratospheric ozone to some extent	Non-Toxic
7	Market Availability	Yes	Yes	Yes
8	Nature Conservation	Low	Medium	Low
9	Fire Resistance	Class A1	Class A BS3837, Part 1, 1986	Class A ASTM E-84
10	Useful life	Long	Long	Long

From the results reported in Table 5, in terms of thermal conductivity, it can be seen that the extruded polystyrene and polyethylene have less conductivity in comparison with the glass wool. Polyethylene is also more cost-effective than the other two types of insulation materials. In case of ease of application and environmental impact, polyethylene has better performance than extruded polystyrene and glass wool. As extruded polystyrene is a recyclable material, therefore it has more recyclability and energy efficiency as compared to the other two materials.

3.4. Multi-Weighted Decision Model

A multi-weighted decision model was developed to make the final decision regarding the most preferred insulation material option for residential buildings in northern areas of

Pakistan. The scorecard for each insulation material was developed individually, where the higher score shows the better efficiency, and then a comparative analysis was conducted, the results of which are shown in Table 6. However, to gain a better insight into the qualitative data the weighted score approach was adopted. Table 7 shows the weighted score (out of 100) and the most effective insulation material is “Polyethylene” and the least effective is “Extruded Polystyrene”.

Table 6. Weighted score card for glass wool, extruded polystyrene and polyethylene.

Sr. No.	Criteria	Weight-Age	Glass Wool		Extruded Polystyrene		Polyethylene	
			Un-Weighted Score	Weighted Score	Un-Weighted Score	Weighted Score	Un-Weighted Score	Weighted Score
1	Cost-Effectiveness (market survey)	20%	37	7.37	21	4.29	100	20
2	Thermal Performance (experimentation)	30%	75	22.5	75	22.5	100	30
3	Thermal Conductivity (literature)	5%	100	5	50	2.25	75	3.75
4	Space efficiency (observation)	10%	50	5	50	5	100	10
5	Ease of application (observation and expert opinion)	5%	50	2.5	75	3.75	100	5
6	Environmental impact (literature)	10%	25	2.5	50	5	50	5
7	Market Availability (observation)	5%	100	5	100	5	100	5
8	Nature Conservation	5%	50	2.5	50	2.5	50	2.5
9	Fire Resistance (literature and expert opinion)	5%	100	5	75	3.75	75	3.75
10	Useful life (literature and expert opinion)	5%	100	5	100	5	100	5

Table 7. Comparative analysis of scorecards of three test materials.

Description	Glass Wool	Extruded Polystyrene	Polyethylene
Weighted Score on a scale of 100	62.37	54.04	90.0

In Table 6, ten factors were evaluated in the scorecard, which was derived from an extensive literature review and through interviews with experts from the local residential construction industry within Pakistan with experience in cold regions. The weightage is given to the mentioned parameters based on the expert’s opinion for their priority to be selected better by the end-user than the other study materials. For assigning the weightage of each element of the scorecard, the relevant information was obtained through interviews with 20 respondents from the local community of Murree, field experts (Architects) of the same region, and the manufacturers who supplied all three insulation materials. The collective response from the multi-party provides the opportunity to determine the viability of the proposed insulation material for residential construction.

A comparative analysis of the outcome from the response of all interviewees was evaluated for recording the best-performing insulation material. According to the scorecard of the multi-weighted decision model, polyethylene was found to be the best insulation material among all others, which has a superiority of results by around 30%, when compared to the other insulation materials (see Table 7).

4. Conclusions

In this study, three commonly and commercially available insulation materials, glass wool, extruded polystyrene, and polyethylene were experimentally evaluated for a case study residential building located in a cold region of Pakistan. Thermal data was collected for 21 days in the year 2019 and was then used for analyzing the performance of each of the three types of insulation materials using a Testo Saveries System. As per performance analysis;

- Polyethylene showed the best performance compared to the other two types of insulation materials in terms of its thermal efficiency.
- Moreover, polyethylene with aluminum foil was proved to be the most cost-effective insulation material in comparison to glass wool and extruded polystyrene materials.

However, to determine the effectiveness of the results, a comparative analysis was performed based on ten different parameters including thickness, cost, thermal efficiency and conductivity, environmental impact, use and application, space efficiency, fire resistivity, and others for each of the three different types of insulation materials. It was found that polyethylene is the most efficient insulation material amongst the other materials for the case study building based on multi-weighted decision model and hence recommended for application in buildings around cold regions of Pakistan.

5. Future Research

The following recommendations are given for extending this research:

- In this study, the average temperature difference of 3–4 °C was recorded with insulations of 12–25 mm thickness. The study can be extended with larger thicknesses to evaluate the improvement in thermal performances with the increase of thickness.
- Further studies are recommended to be conducted in the hot regions of Pakistan and other counties around the world by using the same insulation materials to evaluate the best insulation material concerning its thermal efficiency, cost-effectiveness, and space efficiency.
- Additionally, further research can be conducted in the test rooms of the case study building with the same orientation so that more precise results can be obtained.

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