

Selection of the Wall Optimum Insulation in Light Steel Frame Structure by Analytical Hierarchy Process (AHP)

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Abstract

Light steel Frame System which is made of cold formed steel is one of the best methods of constructing in contrast to the traditional methods because of lower price, high velocity of constructing, saving on materials, natural sources and energy, creating job, materials lower waste, being light, more safety against earthquake, having more compatibility with environment and easier recycling. The structures which have constructed by light steel frame system, have the same problems such as insulation. Using suitable insulation is so vital because there is a cavity between the internal and external walls. These building residents dissatisfy with this new structures because unsuitable insulation causes to enter cold, heat and noise. In order to consider more, we have inquired about four contracting companies which construct the light steel frame structure and attend in the first Iran industrialization project by questionnaire and interviewing; And also the four insulations; rock wool, glass wool, poly urethane, polystyrene which are usually used in the structure walls, have compared by the multi criteria decision making technique of analytical hierarchy process (AHP) in order to select the best insulation. The results show the polystyrene insulation has been accepted more by contractors.

Key words: light steel frame (LSF), thermal and acoustical insulation, analytical hierarchy method (AHP), building industrialization.

1. Introduction

Insulating causes to save the energy in the building. The insulating price and saving energy are the important problems which should be considered in insulating. Using suitable materials in light steel frame system cause to save fuel and energy in building. The insulating in light steel frame structures is highly important and unsuitable insulation causes to enter heat, cold and noise into the building that makes dissatisfied the residents with this structure.

Because thermal movement of the light steel frame with the environment is done by the cold-formed metal sections and the cavity between the walls, so it can create situation for decreasing the thermal movement of this structure with the environment by the standard insulation between the internal and external wall cover and using standard materials for covering the internal and external walls [5]. In order to control the structure deadening, the heavy and light insulations can be used as well as filling the cavity of the walls, because the tighter the wall and the more mass has the more interceptor acoustic drop. The used standard materials for covering the internal and external walls is one of the essential activities in controlling the light steel frame system deadening [6].

2. The Necessary Insulations in the Light Steel Frame System

It is necessary and vital to use insulations in light steel frame structures because there is a cavity between the walls. The insulations which are usually used in these structures, are: rock wool, glass wool, polyurethane and polystyrene.

2.1. Polystyrene

Polystyrene is a white material and the humidity and noise as it made for the first time by Nazi Germany in II world war in order to make floating bridges. Polystyrene foam is one of the products in petrochemical industries and is made of very small crystals which expands by compression and vapor. Polystyrene blocks resist well against water and as well as degeneration and bacterial growth because it has a closed cellular structure. Polystyrene blocks have been used for building construction specially in high apartments in our country by developers because they are light and cheap. There are two kinds of the blocks, the first kind is flammable and the second one is nonflammable. Safety of the residential places against firing and accident is the case which should be considered as a rule of the city safety. Many things play important roles in building safety which one of the most important one is the used materials. Polystyrene blocks decreased the final weight of the building because they are light and as a result they are used in building construction. But these insulation miss their volume easily against fire and the only problem for them is that they show less resistance against the fire and firing. If the best kind of these blocks are used in the building construction, they would have been more resistant against the fire [3].

2.2. Polyurethane

Polyurethane is a set of very important polymers which has special physical properties such as resistance against tearing and erosion, high tensile and adhesiveness capacity and also good resistance against oils, is used a lot in different industries. Also the other properties of polyurethane such as very high resistance against erosion and high resistance against heat, cold, humidity and noise as well as being light and having high elastic property have caused to use increasingly in constructing industries in all over the world. Polyurethane has better effectiveness for a long time use and reduce the applied energy, as a result all the primary costs will compensate. So the advantages are [2];

A. The highest thermal conductance – resistance coefficient among organic and mineral insulations (for example 2 centimeters performance of polyurethane equal with 3/6 centimeters of polystyrene).

B. Lack of implantation insects (This characteristic was wise versa about polystyrene and insects like interior beetles desire to make a cell and ovulate in polystyrene).

C. Suitable acoustic insulation

D. Lack of water and humidity absorption

E. Suitable price

F. Reduce the building dead load

2.3. Glass wool

This material is made of the melted glass and change into very small fibers. This fiber is made in a form of panel or roll and is send to the market. This kind of the insulation has different types and diverse applies and it is installed by constructor's recommendations. The glass wool is cut and installed easily. Estimations show that 9 centimeters of the glass wool thermal insulation equals 3 meters cement in which to reduce the used energy and prevent heat loss inside the building and also reduce the noise inside the building. If we spend only %2 more of glass wool insulation in the building construction, we can save %40 energy. The advantages are [4].

- **Thermal insulation:** The glass wool resists against heat as an insulation. The surfaces which are insulated by it, use lower energy for heating and cooling the internal space in winter and summer respectively by reducing and slowing thermal transmission flow. The more thermal resistance results in the better quality. The glass wool thermal resistance has a direct ratio by its thickness and reverse ratio by thermal transmission coefficient.

- **Acoustic insulation:** The glass wool is resistant against noises diffusion as if the glass wool by a 100 millimeters thickness can increase the sound transmission controlling index between 4 to 12 steps. If we use the glass wool in the sided walls of the ceiling and the floor, it will control annoying waves influence and has optimum effect on relaxation, rest, sleep and finally on the quality of life.

2.4. Rock wool

The primary material for producing the rock wool is diabase or basalt, the most famous igneous rock. This material reminds from volcanic activities which is a lot in Iran. The rock wool is more compacted than the glass wool and has more thermal resistance. It is a good acoustic insulation too. Its production, supply and installation is like the glass wool and is resistant against fire very much. Its apply is the same as the glass wool.

3. Research Method

Every study or research use special methods and tools according to its nature and purpose. In fact having a clear understand about doing an activity is one of the most normative and logical ways for starting an activity searching isn't exception too. One of the most important qualities which should be considered in any kind of scientific research, its true construction that this needs to use a suitable research methodology. One of the best methods in a decision making domain of engineering and construction management is Analytical Hierarchy Process method (AHP). In this research, in order to use (AHP) method and measure its criteria and options in one hand and in order to meet the expert's ideas in the related fields of the research in the other hand, it has been decided to analyze the research goals purposely by creating consensus and uniformity between the experts. Also the information which has been gathered for this research is according to the field method. The primary data has been gathered by documentation and providing questionnaire of conductors and four contracting companies of the light steel frame structures which is done in the first industrialization project in Iran. The four insulations such as rock wool, glass wool, polyurethane and polystyrene which are usually used in the light steel frame system, are compared by AHP method in order to determine the level of their acceptance and effectiveness.

3.1. Analytical Hierarchy Process method (AHP)

Three general steps should be done in order to solve a problem by (AHP) method. First step draws Hierarchy tree that includes purpose, options, criteria and subcriteria. In the second step, the relative importance of different factors should be determined and the evaluation of these factors can be by a decision maker or designers of the problem. The priority of the option is gained after some steps.

4. Results

In order to compare and select the best option, first the comparing criteria should be determined. So the expert's and contractor's ideas who have attended in Iran first industrialization project, has been used to select the criteria. According to the questionnaire and gathered data, these five following criteria have been considered by most of the experts; and include:

1. Heat: It shows the level of the thermal heat which transmits from the insulations.

2. Noise: (Acoustic): It shows the level of noise which transmits from the insulation.

3. **Humidity:** It shows the level of the insulation resistance against humidity.

4. **Cost:** It shows which insulation is cheaper than the others.

5. **Installation:** It reveals the conducting velocity and easy installing of the insulations.

4.1. **Drawing the analytical hierarchy process tree AHP**

The tree of the (AHP) method can be drawn by determining the criteria and the options.

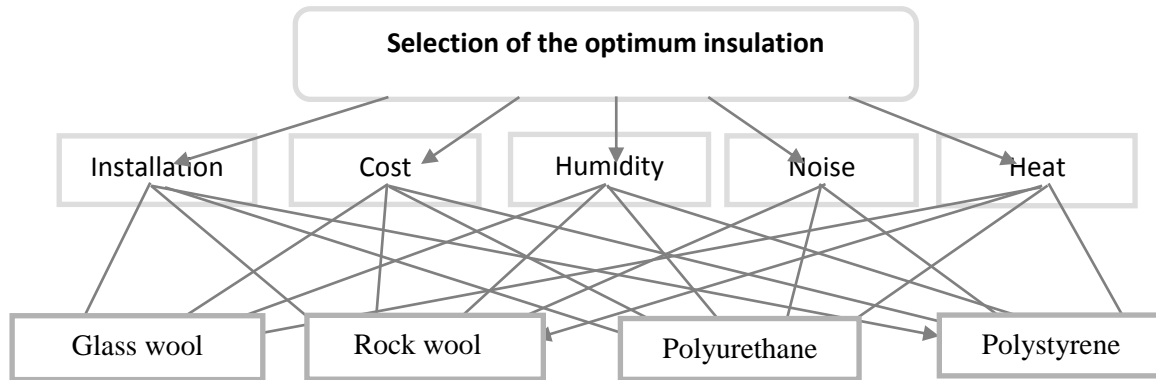


Figure1. Drawing the Analytical Hierarchy Process Tree (AHP)

4.2. **Paired comparing of the criteria**

After selection, the criteria should be compared together. So the four contractors who had constructed these insulations before, have been surveyed by interview and questionnaire and the acceptance level of these criteria has been scored. This questionnaire which use for hierarchy analyses and multi criteria decision making is called certified questionnaire.

The certified questionnaire not only isn't complicated at all, but also it's so easy. In order to provide a certified questionnaire, the paired comparing of the criteria are used. One certified questionnaire is provided for every step of this hierarchy process. Clock nine quantity scale is used for scoring.

Table 1. Clock nine quantity scale

value	comparing <i>i</i> to <i>j</i> criteria	explanation
1	the same preference	the <i>i</i> index is as important as the <i>j</i>
3	not much better	<i>i</i> index or option is more important than <i>j</i> less
5	better	<i>i</i> index or option is more important than <i>j</i>
7	not complete better	<i>i</i> option is more important than <i>j</i> very much
9	completely better	<i>i</i> option is the most important one

Weight of every criterion is measured after paired comparing criteria. In order to understand better about analysis method of the contractors' ideas, the idea of the contractor has been considered as an example.

A. After completing the table, algebraic sum of every column is written at the final row.

Table 2. The paired comparing of the criteria

	heat	noise	humidity	installation	cost
heat	1	1.3	7	5	1.9
noise	3	1	7	9	1.5
humidity	1.7	1.7	1	1.5	1.3
installation	1.5	1.9	5	1	1.7
cost	9	5	3	7	1
total	4.13	6.58	23	22.2	1.78

B. After gathering the values, soft sum every cell of the table is gained (by division of every cell into algebraic sum of the same column).

Table 3. The gained results from division of every cell into algebraic sum of the same column in table 2

	heat	noise	humidity	installation	cost
heat	0.075	0.05	0.304	0.22	0.062
noise	0.22	0.151	0.304	0.405	0.11
humidity	0.01	0.021	0.043	0.009	0.186
installation	0.014	0.016	0.217	0.044	0.08
cost	0.674	0.759	0.13	0.315	0.059
total	1	1	1	1	1

C. In this stage, algebraic sum of every row shows the normal weight of every criterion according to the contractor's idea.

Table 4. The gained results of the weight of every criterion

	heat	noise	humidity	installation	cost	total of rows
heat	0.075	0.05	0.304	0.22	0.062	0.1422
noise	0.022	0.0151	0.304	0.405	0.11	0.238
humidity	0.01	0.021	0.043	0.009	0.186	0.051
installation	0.014	0.016	0.217	0.044	0.08	0.0742
cost	0.674	0.759	0.13	0.315	0.059	0.4936
total	1	1	1	1	1	1

Table 5. calculation of the criteria importance according to the contractor's idea

	Contractor1	Contractor 2	Contractor 3	Contractor 4	mean
heat	0.1424	0.1403	0.1465	0.1397	0.1421
noise	0.238	0.249	0.224	0.231	0.228
humidity	0.051	0.073	0.047	0.058	0.056
installation	0.0742	0.063	0.084	0.0767	0.076
cost	0.4936	0.5106	0.4872	0.5084	0.5001

After gaining the weight of the criteria, these steps are done for all the contractors too and the total weight of all criteria are determined by mean of the contractors' idea which results have been shown in the table4. Order of the criteria are determined according to their importance and value and by mean column.

1.Cost (0.5001), 2.Noise (0.228), 3.Heat (0.1421), 4.Installation (0.076), 5.Humidity (0.056).

When the important level of the criteria are determined than each other, then the options are compared by every criterion separately.

Table 6. The options comparison together according to the cost

	rock wool	glass wool	polyurethane	polystyrene
rock wool	1	1.3	3	1.7
glass wool	3	1	3	1.3
polyurethane	1.3	1.3	1	1.5
polystyrene	7	3	5	1

Table 7. soft calculation of every cell according to the cost

	rock wool	glass wool	polyurethane	polystyrene
rock wool	0.088	0.714	0.25	0.0852
glass wool	0.264	0.2142	0.25	0.199
polyurethane	0.294	0.0714	0.083	0.199
polystyrene	0.617	0.642	0.416	0.596
total	1	1	1	1

Then by summation of every row and meaning like the table 4, the importance of the options are determined according to the cost. These steps are done for the other criteria in order to find the option importance than the other criteria. The cost criterion has been shown as an example.

Table 8. The importance of the options than each other by calculating the cost criteria

	rock wool	glass wool	polyurethane	polystyrene	total of rows
rock wool	0.088	0.714	0.25	0.0852	0.1236
glass wool	0.264	0.2142	0.25	0.199	0.2318
polyurethane	0.294	0.0714	0.083	0.199	0.0757
polystyrene	0.617	0.64	0.416	0.596	0.5676
total	1	1	1	1	1

Table 9. Table for the insulation scores than costs according to the contractor's idea

	Contractor 1	Contractor 2	Contractor 3	Contractor 4
rock wool	0.1236	0.1135	0.1301	0.1179
glass wool	0.2318	0.2059	0.2268	0.2534
polyurethane	0.0759	0.0926	0.0842	0.0798
polystyrene	0.5636	0.5838	0.5589	0.5486

After calculation of the insulation scores the criteria, the final score of every option (insulation) is calculated by relation (1)

$X_{ij} = i$ according to the criterion j of the insulation score.

The final score of every insulation = $\sum_{i=1}^4 X_{ij} W_i$ relation (1)

Rock wool = $0.3991 \cdot 0.056 + 0.1408 \cdot 0.076 + 0.4652 \cdot 0.1421 + 0.3681 \cdot 0.228 + 0.1236 \cdot 0.1421 = \mathbf{0.12415}$

Glass wool = $0.1174 \cdot 0.056 + 0.076 \cdot 0.2574 + 0.228 \cdot 0.2057 + 0.1421 \cdot 0.1518 + 0.5001 \cdot 0.2318 = \mathbf{0.2044}$

Polyurethane = $0.056 \cdot 0.2886 + 0.076 \cdot 0.1746 + 0.228 \cdot 0.3492 + 0.1421 \cdot 0.3265 + 0.0757 \cdot 0.5001 = \mathbf{0.1858}$

Polystyrene = $0.056 \cdot 0.2546 + 0.076 \cdot 0.4268 + 0.228 \cdot 0.077 + 0.1421 \cdot 0.0551 + 0.5001 \cdot 0.5976 = \mathbf{0.3709}$

These scores include the idea of the first contractor. For the next contractors, the above steps are done and selected the best option by meaning.

Table 10. Selection of the optimum insulation

	Contractor 1	Contractor 2	Contractor 3	Contractor 4	the score mean
rock wool	0.2415	0.2354	0.2507	0.2483	0.2440
glass wool	0.2044	0.2147	0.1926	0.2013	0.2032
polyurethane	0.1858	0.1732	0.1894	0.1944	0.1857
polystyrene	0.3709	0.3767	0.3671	0.3560	0.3651

As you see, the polystyrene insulation was selected as the best option with the most score (0.3651)

5. Conclusion

The purpose of this research was to select a suitable insulation by multi criteria decision making of AHP method, in order to solve the problem of the noise and heat transmission in the light steel frame. The polystyrene insulation was selected finally after considering ideas and analyzing the data by AHP method. So it can be said this insulation is acceptable more than the other ones among contractors and conductors of the light steel frame. But this insulation isn't a suitable insulation for noise and heat transmission in the light steel frame structure because its thickness isn't very much and there is a cavity between studs and so the next options such as rock wall and polyurethane are more suitable insulations for solving the problem of insulating in the light steel frame structure. There are some reasons for selecting polystyrene by contractors and conductors of the light steel frame structure:

5.1. Selection of owner- contractor agreement

Its acceptance depends to the kind of the contracted agreement with the contractor which is EPC. In this kind of agreement, the contractor is responsible to provide the second phase plan, so the contractors have used polystyrene in order to decrease the costs and construct in high velocity. This insulation is cheaper than the other ones and its installation velocity is high. But this isn't a suitable insulation for noise and heat transmission in the light steel frame structure because its layer is thin and there is a cavity between the studs and if the contracted agreement was according to the other kind in which the second phase plans are considered more carefully by the owner, the better insulation can be selected to solve the problem in insulating of the light steel frame structure.

5.2. Be new and first experience for constructing Iran industrial structures in a form of Mehr resident

The technology for these structures have been imported to Iran from different countries, but necessary training for constructing haven't been imported completely. Also when this project entered into the country in the form of Mehr resident and because the prices were fixed and the insulations were

expensive too, the contractors didn't consider the related standards of these structures and as a result they used the unqualified insulations.

5.3. Lack of infrastructure and shortage in the primary materials

The government and the constructing companies should provide infrastructures such as constructing factories for producing primary materials, in order to decrease the final time and cost of the construction. These constructed factories can create jobs in the country as well as producing the primary materials. If these infrastructures aren't provide, it would have been caused to import materials from other countries which are too expensive according to the importing costs. So the contractors use the unstandardized insulations and materials because the imported materials are so expensive and as a result decrease the quality of these instructors.

5.4. Lack of the training centers for training the constructing personnel like technical and professional centers.

We can't use traditional masons and workers because the materials is used to construct the light steel frame structure and there aren't any brick, soil and other things [1]. For example lack of the technician and expert for constructing this light steel frame structure has caused that studs and joists weren't adjusted, so the wall insulating isn't done well. Then the training courses should be held by technical and professional centers to train the experts. If there were technical experts for constructing this structure, the installation and assembly will be done by the best quality and in the shortest time.

5.5. Lack of localization in the light steel frame system

Technical considerations should be done before constructing these structures to provide a situation for the resident's welfare. We must make ready the necessary fields for the residents of these houses by changing in the second phase plans (according to the building insulation standard) and localizing according to cultural traditions of Iran. Also people should be familiarized with the advantages of this new structure by holding fairs and advertising in media in order to be accepted by society.

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