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COMPARATIVE THEORETICAL HEAT TRANSFER STUDY OF DIFFERENT INSULATING MATERIALS IN MULTILAYER WALL FOR ENHANCING BUILDING THERMAL EFFICIENCY

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Abstract:

Buildings are aimed to provide shelter against the weather and climatic vagaries but at the same time a good building construction should provide thermal comfort in an energy efficient way. One of the major components of building envelope is walls which plays an important part in heat transfer. If thermal resistance of walls is high the indoor environment can be maintained at desired levels of temperature with minimum energy requirements. In order to improve the building thermal efficiency it is important to improve the thermal resistance of the walls through use of suitable insulating materials. This paper presents a comparative theoretical heat transfer study of different insulating materials in walls. The materials chosen for study are aerogel, rockwool, glass wool, sheep wool, hemp, flax, slag wool, fiber glass, phenolic foam, vermiculite, PUF/PIR foam, polystyrene foam, sawdust, perlite, polyester, cardboard and cork. Present study introduced multilayer of cement plaster, red brick/flyash brick, cement plaster, plywood, insulating material layer and gypsum board i.e. six layers combination have been introduced in which all layers are same except fifth layers which is varied by different insulating materials. From the study, it can be concluded that red brick wall and flyash brick wall without insulating layer has higher heat transfer although flyash brick wall has lower heat transfer than red brick wall. In case of red brick wall, wall with aerogel has the lowest heat transfer and it is 2.53 W at 10^0C and 7.60 W at 30^0C and wall with vermiculite has highest heat transfer which is 9.28 W at 10^0C and 27.83at 30^0C. In case of flyash brick, wall with aerogel has lowest heat transfer which is 2.43 W at 10^0C and 7.28 W at 30^0C and wall with vermiculite has highest heat transfer which is 7.97 W at 10^0C and 23.91 W at 30^0C.

Key Words: Thermal Conductivity, Insulation, Temperature, Thermal Resistance, Heat Transfer & Thermal Comfort

1. Introduction:

With increase in population and urbanization, past few decades have seen rise in buildings to provide more space and accommodate more, keeping the cost low. In all these efforts the thermal comfort of a building has become more dependent on electro-mechanical devices. The electricity consumption of buildings is rising at a fast pace thus it becomes necessary to use new techniques for enhancing thermal comfort in buildings in India. Building envelope in itself can act as a major determinant in improving thermal comfort if proper passive measures are adopted. Raman et. al. describe the development of a solar passive system which can provide thermal comfort throughout the year in composite climates. Two passive models have been studied, passive model 1 comprising of two sets of solar chimney and in passive model 2 both trombe wall and sack cloth cooling concepts were incorporated [1]. I.L. Wong et al discussed transparent insulation system for building applications, drawbacks to previous applications, cost trends and analysis of the limitation in information from previous studies [2]. D. H. W. Li and S. L. Wong investigated the shading effects due to nearby obstruction when day lighting schemes are being employed [3]. S. Chungloo and B. Limmeechokchai studied the benefits of application of solar chimney on the south roof and cool metal ceiling on the north roof through the experiment in a detached building called a controlled cell, and a related numerical model has been constructed from computational fluid dynamics (CFD) program [4]. R. V. Ralegaonkar and R. Gupta reviewed intelligent building construction with the aid of passive solar architecture approach, which makes use of specific building design principles and reduces the artificial energy requirements for achieving indoor thermal comfort [5]. M. A. Kamal reviewed and analyzed various passive cooling techniques and their role in providing thermal comfort and its significance in energy conservation [6]. N. B. Geetha and R. Velraj reviewed the various possible methods of passive cooling for buildings and discussed the representative applications of each method [7]. By applying layers of high performance insulation on wall of building thermal comfort in building with low energy consumption can be achieved. Xiaolu Li et al. introduced lightweight steel structure residential housing which has the property of green, energy saving, environmental protection. They analyzed and studied lightweight steel structure residential building in North America, Japan and Europe. Then according to particular condition in China, development status and properties are introduced in lightweight steel structure residential building, including some traditional housing concept, and intensive steel residential building. They introduced multilayer of latex, putty, gypsum board, rockwool, breathing proof paper, wooden, extruded plate, OSB rally edition and metal carved panels with light steel keel [8].

Laszlo Bax et al. introduced five solutions from chemical industry that can bring significant energy savings which are 1) reflective indoor coating 2) high reflectance and durable outdoor coating 3) phase change material (PCM) 4) new insulation foams 5) other insulation modules. According to them, advanced or new insulation foam can reduce energy cost for heating by 30%-80%. [9].

In the present paper focus is on multi layers building walls, in which different insulating layers are combined with brick wall. One of the major components of building envelope is walls which plays an important part in heat transfer. If thermal resistance of walls is high the indoor environment can be maintained at desired levels of temperature with minimum energy requirements. In order to improve the building thermal efficiency it is important to improve the thermal resistance of the walls through use of suitable insulating materials. This paper presents a comparative theoretical heat transfer study of different insulating materials in walls. The materials chosen for study are aerogel, rockwool, glass wool, sheep wool, hemp, flax, slag wool, fiber glass, phenolic foam, vermiculite, PUF/PIR foam, polystyrene foam, sawdust, perlite, polyester, cardboard and cork.

2. Insulating Materials for Building:

Different types of insulation materials can be used on the walls and roofs of the buildings. The table below presents the type of insulation with some example of materials.

Table 1: Different forms of insulation for walls [10]

S.No	Type of Insulation	Insulation Materials
1.	Blanket, batts and rolls	Fiber glass, mineral(rock or slag)wool, plastic fibers, natural fibers
2.	Foam board or rigid foam	Polystyrene, Polyisocyanurate, Polyurethane
3.	Insulating concrete forms(ICFs)	Foam boards or foam blocks
4.	Loose-fill and blown –in	Cellulose, fiber glass, mineral(rock or slag) wool
5.	Reflective system	Foil faced kraft paper, plastic film, polyethylene bubbles, or cardboard
6.	Rigid fibrous or fiber insulation	Fiber glass, mineral(rock or slag)wool
7.	Sprayed foam and foamed in place	Cementitious, phenolic, polyisocynanurate, polyurethane
8.	Structural insulated panels(SIPs)	Foam board or liquid foam insulation core, straw core insulation

Sprayed foam and foamed in place or wall cavity insulation has been applied in northern European countries and becoming financially attractive also in southern part of Europe. Reflective coatings on roof have been used for the last 12 years in a wide number of buildings specially in US [9]. Presently in India the buildings do not usually use insulating materials in walls therefore this work has been undertaken to assess the performance of multilayer wall on basis of heat transfer.

3. Methodology:

With the value of thermal conductivity of material of wall or layer known, the heat transfer or U-value through the wall can be determined using following formula [11]

$$Q = \Delta T/R_T = T_2 - T_1 / R_T \text{ W}$$

Where $\Delta T = T_2 - T_1$ = temperature difference between inner temperature (T_1) and outer temperature (T_2) in ^{0}C

R_T =total resistance (^{0}C /W), $R = \delta/ kA$

Where δ = thickness of layer (meter), k = thermal conductivity (W/mK), A = area of wall (sq.m.)

The present study has been done for steady state condition i.e. inner and outer temperatures are constant. Total resistances are without internal and outer air resistance, but these can be added in total resistances which are as follows

Internal resistance –.13m^{2}K/W

Outer resistance- .04m^{2}K/W (according to ECBC and [12]

Here multilayer walls are studied in which six layers combination are used. In six layer combination first four layers are made of cement, brick, cement and plywood which are common in each study. Fifth layer is used of different insulating materials and sixth layer is of gypsum board which is also common in all study.

Gypsum board is used here because it adds to many features including insulation. It is easy to install, provides fire resistance and sound isolation. It is durable, economical, versatile and can also be used in interior decoration [13].

Plywood is made from multilayer wood veneer so it is very strong material, it does not soak water or liquid very quickly so it is less susceptible to water damage. Plywood is sustainable and holds screw very tightly [14]. Here the heat transfer per unit area has been determined i.e. the area A has been taken as 1 sq.m.

4. Materials and Thickness:

During the present study some materials have been selected for the heat transfer study through multilayer wall. Some combinations of different insulating layers with red and fly ash brick that are commonly used now a days have been selected and the total resistance and heat transfer by using formula given above has been calculated. Thickness, densities and thermal conductivities of materials which are used in this paper are given below.

Table 2: Material properties used in the study

Materials Common in All Studies:

S.No	**Materials**	**Density (kg/m^3)**	**Thermal conductivity((W/mK)**	**Thickness of layers (in m)**
1.	Red brick(double)[12]	2049	1.27	0.23
2.	Fly ash brick (double)[12]	1240	0.64	0.23
3.	Cement plaster [12]	1880	1.21	.012
4.	Plywood[12]	697	0.22	.025
5.	Gypsum board[12]	623	0.25	.015

Different Insulating Materials:

S.No	**Materials**	**Density (kg/m^3)**	**Thermal conductivity (W/mK)**	**Thickness of layers (in m)**
1.	Polyurethane foam/polyisocynurate(PUF/PIR)[12]	40	.04	.05
2.	Expanded/extruded polystyrene [12]	31/30	.03	.05
3.	Rock wool [12]	64	.05	.05
4.	Glass wool[12]	49	.04	.05
5.	Perlite(loose fill)[15]	-	.031	.05
6.	Cork(loose fill)[15]	-	.07	.05
7.	Polyester(semi rigid fiber board)[15]	-	.05	.05
8.	Fiber glass[15]	-	.04	.05
9.	Exfoliated Vermiculite(loose fill)[16]	160-192	.071	.05
10.	Phenolic foam[17]	35	.020	.05
11.	Aerogel[17]	150	.014	.05
12.	Sawdust[18]	200	.0698	.05
13.	Cardboard, corrugated[18]	-	.064	.05
14	Slag wool[18]	250	.0698	.05
15.	Flax(loose fill) [19]	20-100	.035-.045	.05
16.	Hemp(loose fill) [19]	20-45	.040-.060	.05
17.	Sheep wool[20]	14	.042	.05

5. Comparative Study of Heat Transfer:

During this present theoretical study different insulating materials are considered to be introduced between plywood and gypsum board in loose fill or semi rigid form. The wall is considered to be a multilayer wall with six layers. Two cases have been studied, one for red brick and another for flyash brick.

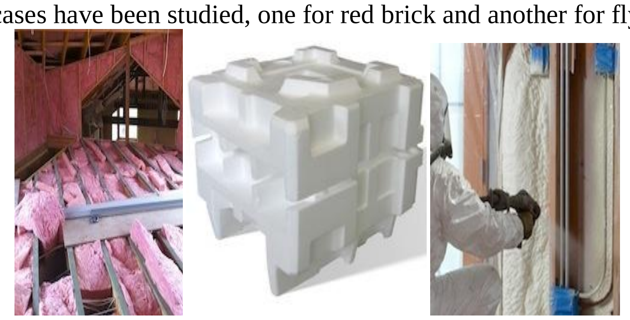

Figure 1: (i) fiber glass (ii) polystyrene (iii) polyurethane foam [21]

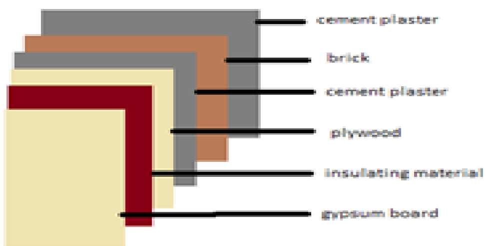

Figure 2: Multilayer wall with six layer of different materials

5.1 Multilayer Wall with Red Brick:

Present study introduced multilayer of cement plaster, red brick, cement plaster, plywood, different insulating materials and gypsum board i.e. six layers combination have been used in which all layers are same except fifth layer which is varied by different insulating materials. Q -factor through multilayer wall with different insulating material have been determined and compared it with Q- factor which is determined through the wall without insulating material i.e. the wall of plaster, brick and plaster. Here wall made of cement plaster, brick and cement plaster has been taken as reference 1 and wall made of cement plaster, brick, cement plaster, plywood and gypsum board as reference 2.

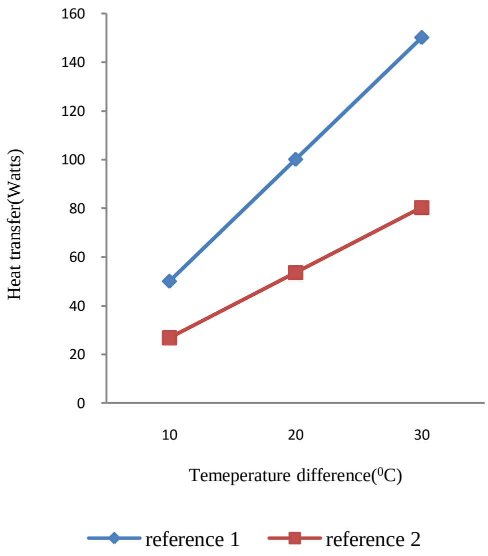

Figure 3: Comparative study of heat transfer at different temperatures through reference wall 1(plaster, brick and plaster) and reference wall 2(plaster, brick, plaster, plywood and gypsum board).

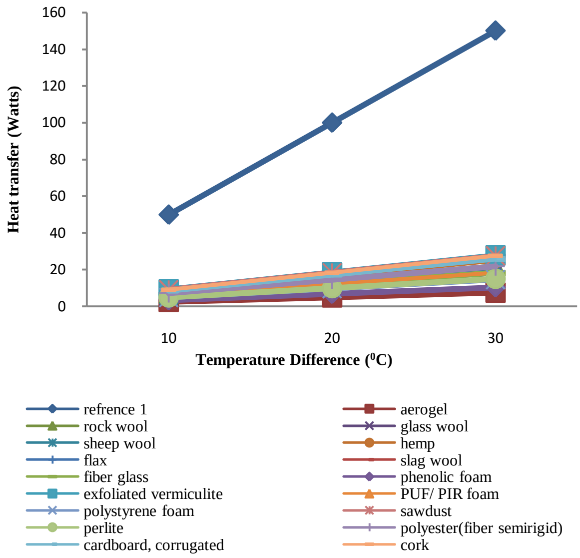

Figure 4: Comparative study of heat transfer at different temperatures (10^0C, 20^0C, 30^0C) for reference wall 1 (plaster, brick and plaster) and six layered wall with different insulating materials in the fifth layer.

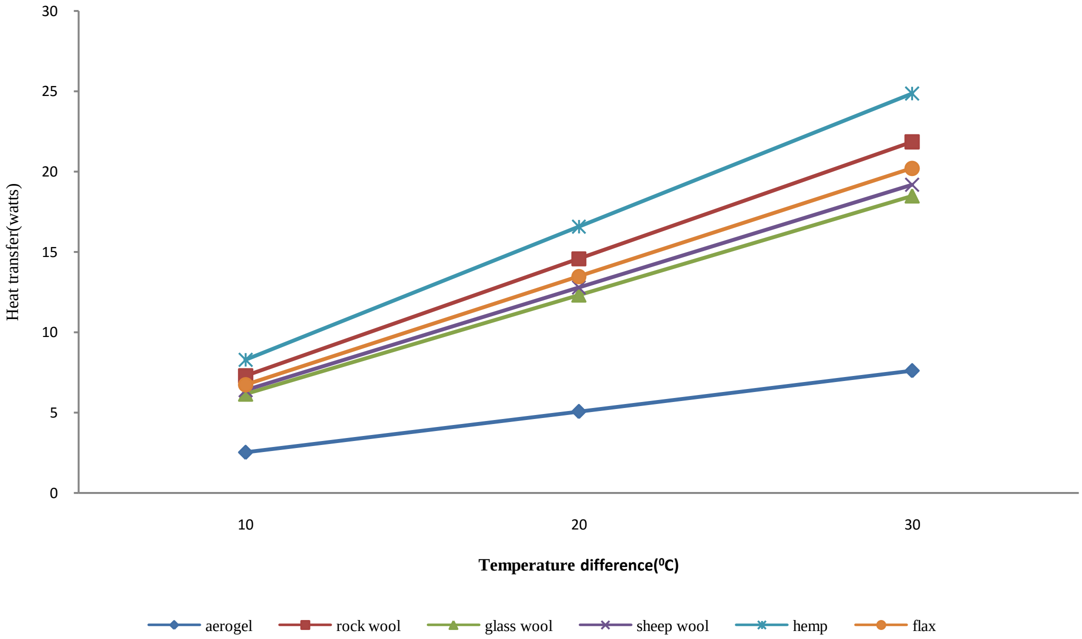

Figure 5: Comparative study of heat transfer at different temperatures for aerogel, rockwool, glass wool, sheep wool, hemp and flax as insulation in multilayer wall

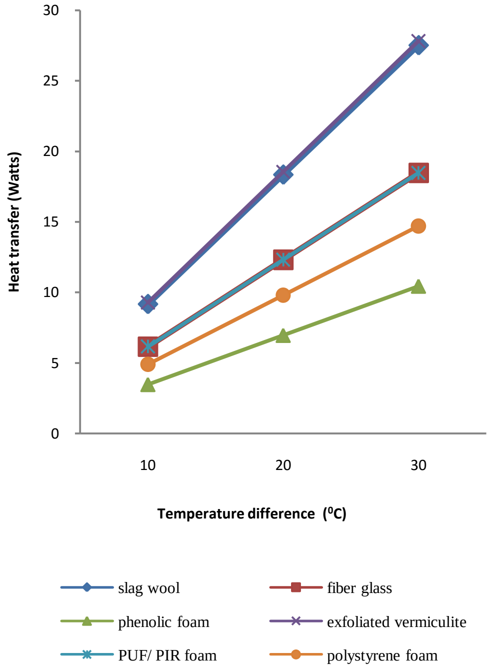

Figure 6: Comparative study of heat transfer at different temperatures for slag wool, fiber glass, phenolic foam, vermiculite, PUF/PIR foam, polystyrene foam as insulation in multilayer wall

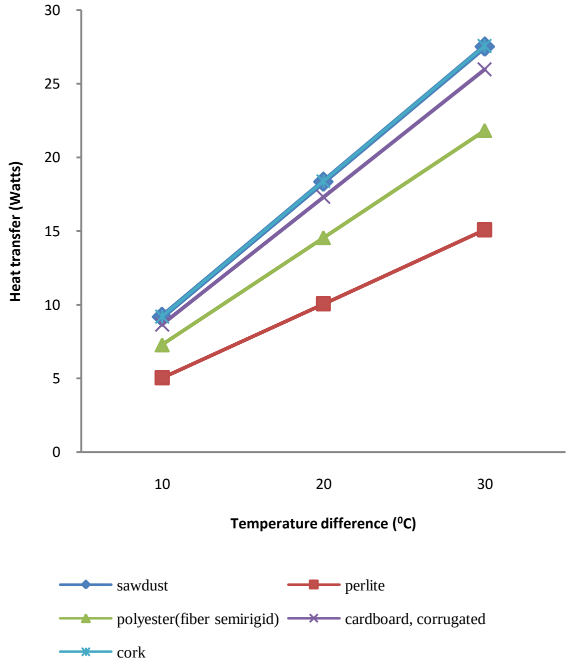

Figure 7: Comparative study of heat transfer at different temperatures for sawdust, perlite, polyster, cardboard and cork as insulation in multilayer wall

5.2 Multilayer Wall with Flyash Brick:

Here flyash brick is used in place of red brick in multilayer.

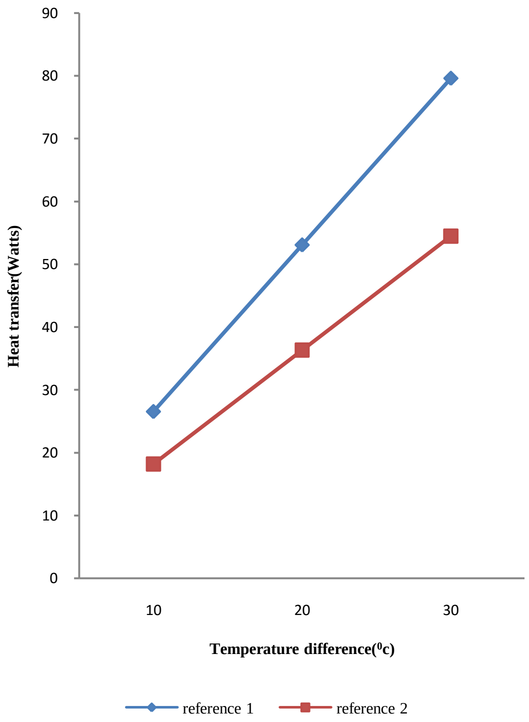

Figure 8: Comparative study of heat transfer at different temperatures through reference wall 1(plaster, fly ash brick and plaster) and reference wall 2(plaster, fly ash brick, plaster, plywood and gypsum board).

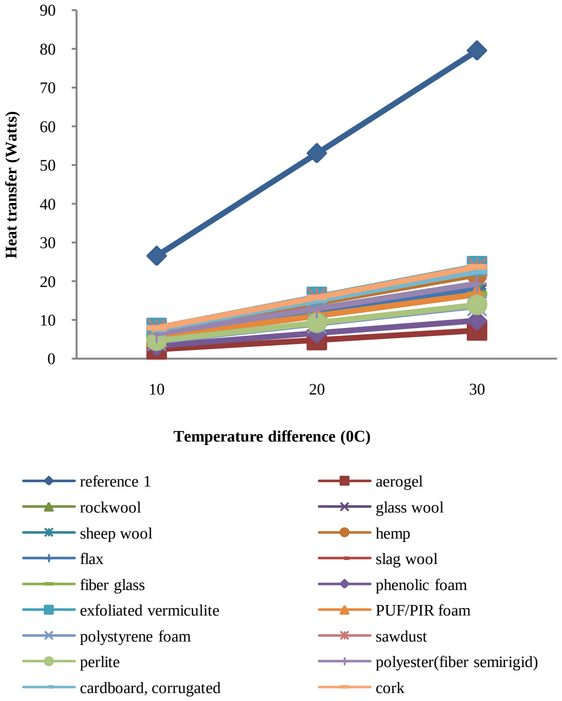

Figure 9: Comparative study of heat transfer at different temperatures through reference wall 1and multilayer with different insulating material

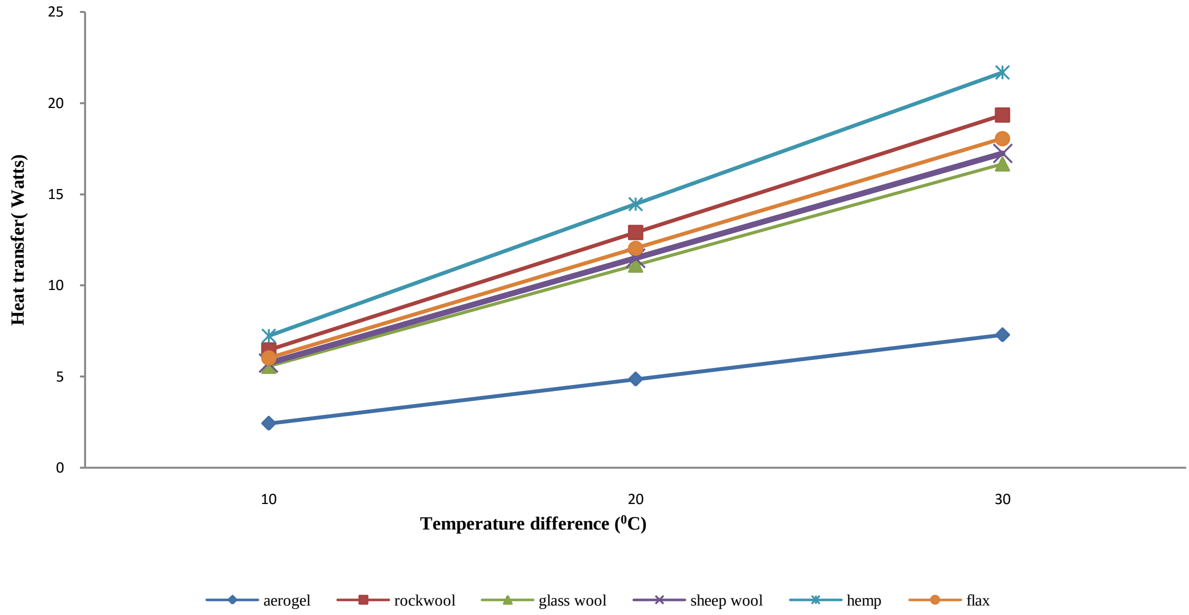

Figure 10: Comparative study of heat transfer at different temperatures for aerogel, rockwool, glass wool, sheep wool, hemp and flax as insulation in multilayer wall

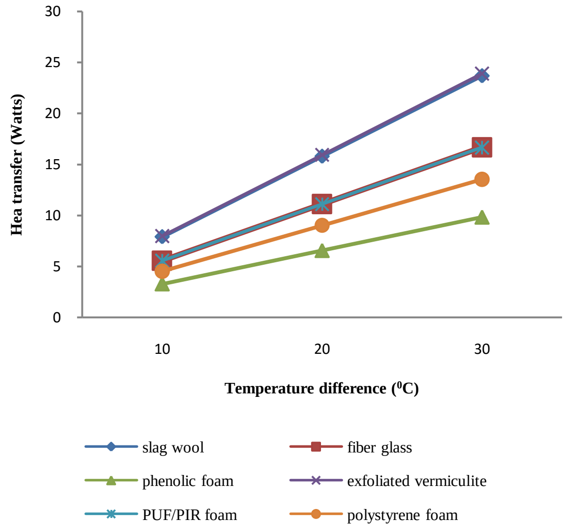

Figure 11: Comparative study of heat transfer at different temperatures for slag wool, fiber glass, phenolic foam, vermiculite, PUF/PIR foam and polystyrene foam as insulation in multilayer wall

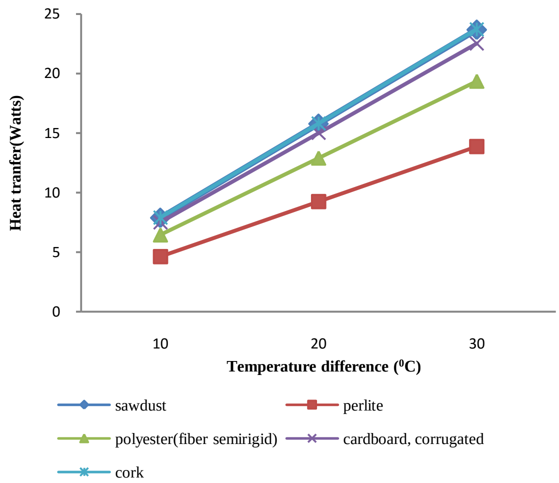

Figure 12: Comparative study of heat transfer at different temperatures for sawdust, perlite, polyester, cardboard and cork as insulation in multilayer wall

6. Result and Discussion:

Figure 3 shows the huge difference between heat transfer through reference wall 1 and reference wall 2. It is clear that the heat transfer almost becomes half with addition of plywood and gypsum board layer to conventional plaster-brick-plaster wall. Fig 4 shows that the wall without any insulating layer i.e wall of brick and cement has very high heat transfer than wall with insulating layers. Wall of red brick without insulating layer has greatest heat transfer at all temperature. On comparing Fig.3 reference wall 2 with the walls with different insulating layers in Fig. 4, it is evident that on introducing a fifth layer of insulating material the heat transfer is further reduced to values less than 30W. Figure 5 shows the comparison of walls with five different insulating layers for aerogel, rockwool, glass wool, sheep wool, hemp and flax. It shows that aerogel has lowest heat transfer than any other material and its minimum value is around 3W at 10^0C temperature while maximum value is around 8W at 30^0C temperature. Glass wool has higher heat transfer than aerogel by around 58%. Sheep wool, flax and rockwool have slightly increased heat transfer value. Hemp has 5% increased heat transfer value than flax and it is around 8W at 10^0C temperature and around 25W at 30^0C temperature.

Figure 6 shows comparison of heat transfer through wall with slag wool, fiber glass, phenolic foam, vermiculite, PIR/PUF foam and polystyrene foam. Phenolic foam has lowest heat transfer than other five materials and it is around 3W at 10^0C temperature and around 10W at 30^0C. Polystyrene foam has higher heat transfer than phenolic foam and it increases by 29%. Fiber glass and PUF/PIR foam has same heat transfer value and it is 20% higher than polystyrene foam. Slag wool has higher heat transfer than fiber glass and PUF/PIR foam and it is 32% higher. Exfoliated vermiculite has higher heat transfer than other five materials and it is around 9 W at 10^0C and around 28 W at 30^0C. Fig.7 shows the comparison of heat transfer through wall with insulating materials perlite, sawdust, polyester, cardboard and cork. Perlite has the lowest heat transfer than other five materials and it is around 5 watt at 10^0C and around 15 W at 30^0C. Polyester has higher heat transfer than perlite and it increases by 30%. Cardboard has more heat transfer than polyster and it increases by 15%. Sawdust and cork almost has same heat transfer and it is higher by some points. Sawdust has highest heat transfer than other four materials and it is around 9 W at 10^0C and around 28W at 30^0C.

Figure 8 presents a comparison of reference walls 1 and 2 for fly ash bricks. It can be clearly seen from Figure 8 and Figure 1 that heat transfer through fly ash brick wall is less as compared to red brick wall and it is interesting to observe the values with different insulating materials. From fig. 9 it is clear that flyash brick wall without insulating layer has higher heat transfer than wall with insulating layers. Fig. 10 shows the comparison of walls with five different insulating layers. The trends are similar as in Fig. 5 but the values are slightly reduced. It shows that aerogel has lowest heat transfer than any other material and its minimum value is around 2W at 10^0C temperature while maximum value is around 7W at 30^0C temperature. Fig.11 shows comparison of heat transfer through wall with slag wool, fiber glass, phenolic foam, vermiculite, PIR/PUF foam and polystyrene foam with fly ash brick wall. Phenolic foam has lowest heat transfer than other five materials and it is around 3W at 10^0C temperature and around 10W at 30^0C. Exfoliated vermiculite has highest heat transfer than other five materials and it is around 8 W at 10^0C and around 24 W at 30^0C. Fig.12 shows the comparison of heat transfer through wall with insulating material perlite, sawdust, polyester, cardboard and cork. Perlite has the lowest heat transfer than other five materials and it is around 5 watt at 10^0C and around 14 W at 30^0C. Polyester has higher heat transfer than perlite and it increases by 28%. Heat transfer increases for cardboard, cork and sawdust. Sawdust has highest heat transfer than other four materials and it is around 8 watt at 10^0C and around 24 W at 30^0C. From the above study it can be easily observed that aerogel, perlite and phenolic foam are best candidates for insulating layers, polystyrene and polyester (fiber-semirigid) can also be used. Hemp, vermiculite, sawdust and cork have heat transfers on the higher side among the materials studied.

Materials which provide insulation have also some benefits and drawbacks- aerogel is more expensive, but it provides best insulation. Fiber glass is cheap but it demands careful handling. Mineral wool is effective, but not fire resistant. Polyurethane is an all around good insulation product, through not particularly eco friendly. Polystyrene is a diverse insulation material, but its safety is debated [21].

7. Conclusions:

From the study, it can be concluded that red brick wall and flyash brick wall without insulating layer have higher heat transfer although flyash brick wall has lower heat transfer than red brick wall. In case of red brick wall, wall with aerogel has the lowest heat transfer and it is 2.53 W at 10^0C and 7.60 W at 30^0C and wall with vermiculite has highest heat transfer which is 9.28 W at 10^0C and 27.83at 30^0C. In case of flyash brick wall, wall with aerogel has lowest heat transfer which is 2.43 W at 10^0C and 7.28 W at 30^0C and wall with vermiculite has highest heat transfer which is 7.97 W at 10^0C and 23.91 W at 30^0C. It can be concluded that aerogel, perlite and phenolic foam are best candidates for insulating layers, polystyrene and polyester (fiber-semirigid) can also be used. Hemp, vermiculite, sawdust and cork have heat transfers on the higher side among the materials studied.

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