Analyzing optimum thickness for combination of two thermal insulation materials for building walls

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Abstract- This paper reports an approach for analyzing optimum thickness for combination of two thermal insulation materials for walls of residential buildings on the basis of life cycle cost. Two thermal insulation materials for achieving contrast purposes can be use as a solution in many applications e.g. if fire resistant material added with Expanded polystyrene (EPS) to improve its fire resistance property, its thermal conductivity increases, where as if we select glass wool as thermal insulation material it has higher thermal conductivity but better fire resistant, thus if we wish to achieve high thermal resistance with better fire resistance at low cost we can use in place of single thermal insulation material a combination of two thermal insulation materials. In order to determine optimum thickness for combination of two thermal insulation materials there is a need to develop an approach, through which optimum insulation thickness for different combination of two thermal insulation materials on the basis of life cycle cost can be analyzed. To study the effect of fraction of one thermal insulation on optimum thermal insulation thickness proposed approach is applied to insulate external wall of a residential building envelope in heating application. Developed total cost objective function analyzed with the help of surface plot. In order to apply the developed approach EPS and glass wool are considered as thermal insulation materials. Through this approach optimum thickness for combination of two thermal insulation materials can be analyzed on the basis of life cycle cost in order to select best combination of thermal insulation materials as per requirement.

Keywords- Combination of two insulation materials; Fraction; Optimum thickness

NOMENCLATURE

\( A_{HPUA} \) - annual heating load per unit area of external wall
\( E_{RPUA} \) - energy required per unit area for heating
\( E_{OH} \) - efficiency of heating system
\( H_{loss} \) - heat loss per unit area of external wall
\( U \) - thermal transmittance of composite external wall
\( T_i \) - temperature inside the building
\( T_o \) - outside temperature
\( HDD \) - heating degree day
\( R_{tot} \) - total wall thermal resistance without insulation
\( x \) - total thickness of thermal insulation materials
\( f \) - fraction of total thickness of thermal insulation materials
\( k \) - thermal conductivity of first thermal insulation material
\( k_1 \) - thermal conductivity of second thermal insulation material
\( HFV \) - heating value of fuel
\( C_{TIPU} \) - total cost of thermal insulation materials per unit area for x thickness
\( C_i \) - cost of first thermal insulation material per unit volume
\( C_{i1} \) - cost of second thermal insulation material per unit volume
\( PWF \) - present worth factor
\( C_t \) - total cost of heating and thermal insulation materials per unit area of external wall
\( C_f \) - cost of fuel per kg

1. Introduction

Issue of energy crisis and increasing cost of energy along with environment concerned lead to need of energy conservation specially in building sector in the form of heating and cooling [1,2]. As far as energy and...
environment is concerned building sector is still most inefficient as compared to transportation sector or industries [9]. As an energy conservation measure in envelope load dominated building thermal insulation of components of building envelope is considered important strategy, with increasing need of heating and cooling for maintaining comfort in hostile climatic conditions [28]. By thermal insulating building envelope cost of heating and cooling reduces but at the same time cost of insulation added. On the basis of life cycle cost analysis optimum thickness of thermal insulation for component of building envelop proposed where total cost of energy and insulation becomes minimum [1]. Optimum insulation thickness leads to maximum saving on the basis of life cycle cost analysis [3]. Thus selection of proper thermal insulation material for component of building envelope and determination of its optimum value for a particular climatic condition becomes subject of interest for many researchers across the world [1-25]. A review of different studies related to economically optimum thickness was presented earlier [26]. In subsequent review need to analyze optimum thickness for combination of two thermal insulation materials suggested [27]. Selection of thermal insulation for different components of building envelopes depends upon various parameters like thermal resistance, cost, fire resistance, moisture resistance, compressive strength and weight depending upon application [28]. On the basis of chemical composition thermal insulation materials can be classified as organic, inorganic, combined and new technology materials [29]. In this work a concept of combined thermal insulation material thickness optimization is proposed on the basis of life cycle cost analysis. Using two thermal insulation materials in combination as compared to single thermal insulation material for external wall has number of advantages. Better quality insulation material from fire resistance, water permeability point of view can be used in the external parts whereas low cost material with inferior quality can be used in inner part in such a combination where life cycle total cost becomes minimum.

2. Structure of external composite wall

In order to analyze optimum thickness of combined thermal insulation material, a brick external wall with outer and inner plaster of a residential building is considered which is common in major parts of India.

![Figure 1. Composite external wall structure](image)

Figure 1, shows the composite external wall considered for present study. In this study inplace of single thermal insulation, two thermal insulation materials are considered. Total thickness of thermal insulation material is divided into two parts i.e, insulation 1 and insulation 2. $f$ is considered as fraction of total thickness of two thermal insulation materials. So out of total $x$ thickness of combined thermal insulation material $f \times x$ is the thickness of insulation 1 and $(1 - f) \times x$ of second thermal insulation material.

3. Annual heating load because of heat loss from external composite wall

In order to calculate annual heating load degree day model is used that is being used by different researchers [1,3,7,15]. Heating load is analyzed for a unit area of external composite wall for ease of comparing the result of any residential building.

Heat loss per unit area of composite external wall is given by [15]
\[ H_{\text{loss}} = U \times (T_i - T_o) \]  

Annual heat loss from external composite wall per unit area is given by

\[ AHLPUA = 24 \times 60 \times 60 \times U \times HDD \]  

Where overall heat transfer coefficient for external composite wall is given by

\[ U = \frac{1}{R_{tw} + (1-f) \times \frac{x}{k} + f \times x/k_1} \]  

4. Requirement of energy for heating of building to compensate heat loss from external composite wall

In order to maintain constant inside temperature of building, amount of energy required for heating is given by

\[ ERPUAFH = \frac{AHLPUA}{EOHS} \]  

Cost of heating to compensate heat loss per unit area from composite external wall on annual basis is given by

\[ ACHPUA = \frac{ERPUAFH}{HVOF} \times C_f \]  

\[ ACHPUA = \frac{(24+60+60+U+HDD+C_f)}{(R_{tw}+(1-f)\times \frac{x}{k}+f \times x/k_1)+EOHS+HVOF} \]  

5. Life cycle cost analysis for optimizing thickness of combination of two insulation materials for external wall

Total cost of thermal insulation materials per unit area, on the basis of fraction of thickness considered is given by

\[ COTIPUA = C_i \times (1-f) \times x + C_{i1} \times f \times x \]  

It has been reported as the cost insulation per unit area increases, cost of heating decreases. In order to determine optimum thickness for combination of two thermal insulation materials total cost per unit area of external composite wall represented by equation (9), need to minimize on the basis of life cycle cost as done in previous studies [1,3].

\[ C_t = ACHPUA \times PWF + COTIPUA \]  

\[ C_t = \frac{(24+60+60+U+HDD+C_f)}{(R_{tw}+(1-f)\times \frac{x}{k}+f \times x/k_1)+EOHS+HVOF} \times PWF + C_i \times (1-f) \times x + C_{i1} \times f \times x \]  

6. Results and discussion

In order to implement the proposed strategy for insulating external wall of residential building data is taken from literature and optimum thickness for combination of two thermal insulation materials is analysed.

Table 1. Parameters used in calculating thickness of combined thermal insulation [21]

| Parameter                  | Value |
|----------------------------|-------|
| HDD in °C-days             | 2614  |
| LPG as fuel for heating    |       |
| \( C_f \) in Rs per kg     | 70    |
| \( HVOF \) in MJ/kg        | 46.04 |
| \( EOHS \) in percentage   | 90    |
| Thermal insulation material 1 - Glass wool | 4279 | 0.038 |
| \(k\) in W/mK | \(C_i\) in Rs/m³ |
|----------------|------------------|
| Thermal insulation material 2 - Expanded polystyrene | 0.032 |
| Total wall thermal resistance without insulation in m²K/W | 0.5858 |
| Present worth factor | 9.05 |

A total cost per unit area of external wall versus combined thickness of two insulation materials with different fraction is plotted. From annual total cost point of view optimum thermal insulation obtained when \(f = 1\), i.e. fraction of Glass wool is 1 and that of EPS is zero than optimum insulation thickness is 0.15 m as shown in Figure 2, which is same as obtained by earlier researcher with same design parameters, where single thermal insulation was analysed at a time [21].

![Figure 2. Total annual cost per unit area versus thermal insulations thickness for \(f = 1\)](image)

Figure 3, shows the variation of optimum thickness of combined thermal insulation materials for different values of \(f\). When \(f = 0\) i.e. thickness of Glass wool is zero then although optimum thickness is 0.09 m but annual total cost per unit area is more as compared to total annual cost per unit area of composite external wall for other values of \(f\). Although in the present analysis cost of glass wool is less as compared to cost of EPS but lower value of thermal conductivity leads to better performance on the basis of life cycle total cost.

![Figure 3. Total annual cost per unit area versus thermal insulations thickness for different fraction \(f\)](image)
7. Conclusion

In the present study an approach to determine optimum thickness for a combination of two thermal insulation materials is proposed with the objective to minimize life cycle cost of fuel and thermal insulation for unit area of external wall of a residential building envelope. Developed approach is applied successfully in heating application. Although optimum value of combination of thermal insulation material on global minima is when \( f = 1 \), which lead to a case of single thermal insulation material. But if space is constrained then designer can use combination of two thermal insulation materials. Thus this approach will be useful in those applications of building thermal insulation where single thermal insulation material not fulfil all the requirements and one property is sacrificed in order to improve the other property, thus combination of thermal insulation materials can be used and their economically best combination can be find out.

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