OPTIMUM INSULATION THICKNESS FOR BUILDING ENVELOPE- A REVIEW

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Abstract

*Through this paper an important issue that what should be the level of insulation for energy conservation in conditioned building envelope is being address. It is well established from the earlier studies of heat transfer across the composite walls that as insulation thickness increases the corresponding resistance to heat flow increases so the rate of heat transfer decreases. The corresponding cost of maintain temperature through artificial means decreases but this is achieve at the cost of insulation which also increases as its thickness increases. The thickness of insulation where total cost of heating/ cooling and insulation cost over the life time becomes minimum is known as optimum insulation thickness. Answer to this question of thermal insulation level in the building envelope components like external wall or roof from economy point of view is being reviewed. Different angles of research in this field being discuss like methods of analyzing annual heating/ cooling loads, insulation material point of view, effect of climate, effect of energy source on optimum insulation thickness. Further different methods used for determination of optimum insulation thickness being reviewed. The effect of solar radiation on optimum insulation thickness is an area which needs further research in Indian context. There is a great need of not only insulating building envelope components like external wall or roof but from economical point of view there is a need to optimize insulation thickness. Further there is need to analyze two insulation materials in combination for maximizing savings***.**

KeyWords- *Optimum insulation thickness, Heating/cooling degree day, life cycle cost analysis, insulation material, external wall.*

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1. INTRODUCTION

In the present scenario where energy and environment are the two most important issues throughout the world every effort should be made to conserve the two. A sector which is most energy inefficient is building sector. In this sector a big share of total energy consumption of a country is used specially in space heating and cooling for maintaining comfortable conditions inside. Now it has been well established that insulation of components of building envelope is one of the most efficient measures for energy conservation in buildings dominated with heat transmission loads. Because the energy requirements are rising with as the standard of living is improving and urbanization is causing construction of more and more buildings throughout the world.

In order to maintain comfortable living conditions in residential buildings more and more artificial means are used during extreme weather conditions but little consideration is given on efficient utilization of this energy in the form of minimizing loss of energy through building envelope. Role of building envelope is very important as this determines the resistance offered against heat gain or heat loss. Earlier high thermal mass buildings were used to regulate the temperature inside the buildings but with the development of construction practices and high strength materials thickness of walls have been reduced considerably that reduces thermal resistance to heat flow. Insulation of different components of building envelope is one of the most appropriate method through which this loss can be minimized. But an important question is what should be the thickness of insulation that should be applied. It is quite clear from the earlier studies of heat transfer across the composite walls that as insulation thickness increases the corresponding resistance to heat flow increases so the rate of heat transfer decreases. A big question before the researchers throughout the world is to optimize insulation thickness for different components of building envelope. To answer this question a systematic approach was developed by A. Hasan [1] according to this work optimum insulation thickness is one where the total cost of heating and insulation becomes minimum over the life time considered. From the equation derived in this work it has been established that the economically optimum insulation thickness is a function of different parameters like cost of fuel, heating degree day, wall thermal resistance, thermal conductivity of insulation material, heating value of fuel, efficiency of heating system and cost of insulation. This work has opened a new door for research. People have done research on economically optimum insulation thickness from different point of view in the light of this fundamental work. In another work K. Comakli and B. Yuksel [3] has shown that optimum insulation thickness can also be defined as a thickness of insulation corresponding to which cost of saving becomes maximum over life time considered for analysis. Later on K.A. Al-Sallal [4] also emphasized on life cycle cost rather than construction budget in order to select a system. Because life cycle cost not only consider initial construction cost but the running cost of heating and cooling of the system [4]. With these two fundamental definitions of optimum insulation thickness number of works have been reported some from climatic conditions point of view, some from different insulation materials point and some from source of energy for heating point of view. In the calculation of optimum insulation thickness two cost factors are involved one energy cost and other insulation cost. In the analysis of energy cost time period for which heating/cooling is required is an important criterion thus some studies concentrated on this aspect. In some studies optimum insulation thickness is analyzed on the basis of heating load in other on the basis of cooling load whereas some studies considered both type of loads. Another angle of research is the environmental aspect and some works reported environment protection potential of optimum insulation thickness from reduction of CO_2 because of conservation of fuel. A number of studies considered insulation of different types of external walls. As far as the different types of walls are concerned it is the thermal resistance that affects the optimum insulation thickness. Some studies considered roof insulation. This paper will review optimum insulation thickness analysis from point of view of different insulation materials considered, different climatic parameters and methods used in the analysis of heating and cooling loads, optimization methods and source of energy used for heating and cooling. Since annual heating and cooling load are important factor in the analysis of optimum insulation loads because it determines the cost of energy saved by insulating component of building envelope. Thus in this review first emphasis will be on different methods used for determining this load.

2. METHODS USED FOR CALCULATING HEATING/ COOLING LOADS AS INPUT PARAMETER

Heating and cooling load is one of the most important input parameter in the calculation of optimum insulation thickness. Because annual heating/cooling energy cost is derived from annual heating/cooling loads. In most of the studies degree time concept is used to determine heating as well as cooling loads [1-3, 5-8, 10-16, 18-20, 22-26]. This method is based on assumption that energy need for building is proportional to difference between outdoor temperature and base temperature, base temperature is the outdoor temperature above and below which cooling and heating is needed (O.Buyukalaca et al. 2001). A. Hasan [1] determined annual heating load from DD method but base temperature was not mentioned in the paper, similarly K. Comakli and B. Yuksel [4] tabled the DD values for three cities without any mentioning base temperature in another study [6] by the same authors for Erzurum DD value was reported but base temperature was not given. Whereas A. Bolatturk [7] taken a base temperature of 15°C for annual heating load calculation for 16 cities from four climatic zones of Turkey. E.H. Ahmad used cooling degree day (CDD) in their analysis [2]. O. Altan Dombayci et al. [8,10] also used DD method for calculating annual energy savings. A. Yildiz [13] et al. used DD method with base temperature of 20 °C for heating load calculations. Further some studies considered effect of solar radiation and surface optical properties of building envelope in the determination of degree day (DD) or degree hour (DH) on the basis of sol-air temperature rather than temperature. In order to analyze annual heating/ cooling load two factors are important, one external climatic condition another time of operation of building. Determination of heating/ cooling load on the basis of DD method depends on the availability of climatic data. But this method lacks in determination of effect of orientation of building envelope component. For accounting effect of orientation there is a need of solar radiation data in order to calculate sol-air temperature. In the work of M.J. Khawaja [5] sol-air temperature is determined with some assumptions for clear sky condition. M.J. Al- Khawaja [5] determines hourly solar radiation data based on astronomical calculations. One dimensional heat conduction equation on the basis of thermal resistance concept was used. Roof was approximated as wall for calculating heat gains, nine months belonging to hot period average solar air temperature was used in the analysis. A. Bolatturk [12] calculated annual energy consumption of building on the basis of DH method with the consideration of solar radiation in terms of solar air temperature. DD or DH method is considered one of the simplest ways for calculating annual consumption of energy because average temperature difference between outdoor and indoor is directly proportional to heat load for a building. A. Bolatturk [7] uses 18 ° C base temperature for the purpose of calculations. Further it is reported that selection of proper base temperature has a significant effect on cooling/heating loads. K.A. Al-Sallal [4] determined annual heating and cooling loads through RECON simulation program. Lollini et al. [9] uses DD method with the consideration of internal gains of the building. J. Yu et al. [16] uses CDD and HDD with the consideration of solar radiation and for heating cooling loads were determined on the basis of cooling and heating period rather than whole year. R.U. Halwatura [17] used simulation DERO-LTH for studying the effect of insulation on building.

Second important parameter is insulation material subsequent part of the paper reviews this aspect

3. INSULATION MATERIALS ANALYSED IN DIFFERENT STUDIES

A. Hasan [1] selected polystyrene and rock wool as an insulation material for external wall, in this study thermal conductivity and cost of material was mentioned and economical optimum insulation thickness was analyzed for a period of 10 years. K. Comakli and B. Yuksel [3] considered stropor as an insulation material for external wall and life time of 10 years was considered for analysis. K.A. Al-Sallal [4] analyzed polystyrene and fiberglass as a roof insulation material. In another study K. Comakli and B. Yuksel [6] considered stropor as an insulation material. In the same period M.J. Al- Khawaja [5] considered wallmate, fibreglass and polyethylene foam as insulation materials for opaque components of building envelope for a period of 25 years although thermal conductivity of materials were not mentioned but the cost was given. A. Bolatturk [7,12] analysed optimum insulation thickness of external wall for polystyrene while expanded polystyrene and rock wool was considered by O. Altan Dombayci et al. [8]. In the study of J. Yu et al. [16] for external wall extruded polystyrene, expanded polystyrene, perlite, foamed polyurethane, foamed polyvinyl chloride were analyzed as insulating material. A. Ucar, F. Balo [15] considered four insulation materials i.e. foamboard 3500, foamboard 1500, extruded polystyrene, fibreglass for external wall. N. Daouas [21] study the effect of wall orientation on optimum insulation thickness of expanded polystyrene. D.B. Ozkan , C. Onan [19] considered rock wool and expaneded polystyrene as insulation material in order to study the effect of glazing percentage on optimum insulation thickness. In Indian scenario some studies on optimum insulation thickness and energy conservation potential being reported are S. Mishra et al. [24] analyzed optimum insulation thickness for external wall for extruded polystyrene and expended polystyrene. In another study by the same authors [23] optimum insulation thickness for external wall and roof was analyzed for glass wool and expanded polystyrene. M. Kayfeci et al. [25] considered Styrofoam, rock wool and glass wool as insulation material in cooling application for external wall. A. Fertelli [26] considered extruded polystyrene and rock wool as an external wall insulation material. Table 1 shows the summary of different insulation materials along with their thermal conductivity which have been used in determination of optimum insulation thickness for building envelope component i.e. external wall or roof in different studies.

Table 1: Shows the summary of different insulation materials analysed in different studies at different places

Reference	**Place**	**Insulation material/ Thermal conductivity (W/mK)**	**Component of building envelope**
A. Hasan [1]	Palestine (West Bank, Gaza)	Polystyrene/0.038 Rock wool/0.043	External Walls
Eball H. Ahmad [2]	Saudi Arabia (Riyadh, Dammam)	Polyurethane/ 0.025 Polystyrene/ 0.032	External walls
K. Comakli and B. Yuksel [3,6]	Turkey (Erzuru,Kars,Erzincan)	Stropor/0.030	External Wall
Khaled A. Al-Sallal [4]	College Station, Texas and Minneapolis , Minnesota	Polystyrene and Fiberglass	Roof
M.J. Al-Khawaja [5]	Qatar	Wallmate, Fiberglass, and Polyethylene foam.	Roof/External Wall
A. Blatturk [7]	Turkey(16 cities from 4 climatic zones)	Polystyrene/ 0.030	External wall
O. Altan Dombayci et al. [8]	Turkey (Denizli)	Expanded polystyrene/0.032 Rock wool/ 0.040	External wall
O. Altan Dombaycı [10]	Turkey (Denizli)	Expanded polystyrene/0.032	External wall
T.M.I. Mahlia et al. [11]	Malaysia	Fibreglass–urethane /0.021 Fiberglass (rigid)/ 0.033 Urethane (rigid)/ 0.024 Perlite/ 0.054 Extruded polystyrene /0.029 Urethane (roof deck) /0.021	External wall
A. Blatturk [12]	Turkey (Adana,Antalya, Aydin, Hatay, Iskenderun, Izmir, Mersin)	Extruded Polystyrene board/0.028	External wall
A. Yuldiz et al. [13]	Izmir (milder climate of the coasts, Ankara (colder climate)	Glass wool and Rock wool	External wall
O. Kaynakli [14]	Turkey (Bursa)	Polystyrene/ 0.034 for external wall, Fiberglass for roof/ 0.038,	External Wall, Roof, Basement
A. Ucar and F.Balo [15]	Turkey (Kocaeli, Aydin, Elazig, Agri)	Foamboard 3500/0.027 Foamboard 1500/0.029 Extruded Polystyrene/0.031 Fiberglass/0.033	External wall
J. Yu et al. [16]	China (Shanghai, Changsha, Shaoguan, Chengdu)	Expended polystyrene/0.05 Extruded polystyrene/0.036 Perlite/0.14 Foamed polyurethane/0.033 Foamed polyvinyl chloride/0.048	External wall
A. Ucar, F. Balo [18]	Turkey (Mersin, Elazıg, Sanlıurfa and Bitlis)	Rock wool/ 0.04, Extruded polystyrene/, 0.031 Nil siding/ 0.118 and Expanded polystyrene/ 0.04	External wall

Ozden Agra et al. [20]	Turkey (Antalya, Istanbul, Eskişehir and Erzurum)	Extruded polystyrene /0.032	External plaster
J. Yu et al. [22]	China (Shanghai, Changsha, Shaoguan, and Chengdu)	Expanded polystyrene/ 0.05, Extruded polystyrene/ 0.036, Foamed Polyurethane/ 0.033 and Polyvinyl chloride/ 0.048	Roof
S. Mishra et al. [23]	India (Imphal, Gwailor, Dehradun, Thiruvanthapuram	Glass wool/ 0.038 and Expended Polystyrene/0.032	External wall Roof
S. Mishra et al. [24]	India (Dehradun)	Expended polystyrene/0.031 Extruded polystyrene/0.033	External wall

Further in order to determine optimum insulation thickness for components of building envelope role of climate is reviewed.

4. EFFECT OF CLIMATE ON OPTIMUM INSULATION THICKNESS

K. Comakli and B. Yuksel [3] investigated optimum insulation thickness for three coldest cities of Turkey. Paper reported that city of Erzuram situated at an altitude of 1758m have heating degree days 4856, whereas Erzincan at an altitude of 1218m have degree days 3458. Results shows that city at higher altitude have more value of optimum insulation rather than one with lower altitude in cold climate. M.J. Al- Khawaja [5] carryout study for Qatar an example of hot place and found wallmate as best insulating material with optimum insulation thickness of approximately 5cm. O. Altan Dombayci et al. [8] has analyzed the optimum insulation thickness for external wall for Denizli that in the third climatic zone of Turkey. Results show that hotter climates have lesser optimum insulation thickness while heating degree days are considered. A. Bolatturk [7] analyzed optimum insulation thickness for external walls of buildings of different cities lies in the first climatic zone of Turkey having warmest summer as compared to other climatic zone, suggested that it should be decided in advance that optimum insulation thickness will be determine either on the basis of cooling or heating load. Results suggested that there is no single value of optimum thickness for a climatic zone but for different cities of a climatic zone optimum insulation thickness is different [7].
Another area of research is the source of energy for heating and cooling, which is being discussed in next section.

5. DIFFERENT ENERGY SOURCES FOR WHICH OPTIMUM INSULATION THICKNESS IS ANALYZED

A. Hasan [1] analyzed diesel as a fuel for heating. K. Comakli and B. Yuksel [3] considered coal as a fuel for heating. O. Altan Dombayci et al. [8] determined optimum insulation thickness for external wall for different energy sources of heating i.e. coal, natural gas, fuel oil, LPG and electricity. A. Bolatturk [7] also analysed optimum insulation thickness for external wall for coal, natural gas, fuel oil, LPG and electricity as heating energy source. In another study O. Altan Dombayci et al. [10] considered coal as a fuel for heating. A. Yildiz et al. [13] also considered coal, natural gas, fuel oil, LPG and electricity as fuel source in their study. A. Blatturk [12] analyzed optimum insulation thickness for external wall with natural gas for heating and electricity for cooling as energy source. O. Kaynakli [14], A. Ucar and F. Balo [15, 18] also considered five energy sources in their study same as A. Bolatturk [7].

Further it is also important to view the research from economical methods point of view to determine optimum insulation thickness in the last section of this paper before concluding the paper.

6. METHODS USED FOR OPTIMIZING INSULATION THICKNESS

In order to optimize insulation thickness for components of building envelope life cycle cost analysis is being performed by different researchers. A. Hasan [1] determined the total cost of fuel and insulation material on the basis of present worth factor method. Then in order to get minimum total cost over life time of this equation is being differentiated with respect to insulation thickness and put equal to zero. Thickness of insulation material corresponding to minimum total cost over life time is the optimum insulation thickness [1]. In this formulation present worth factor is a function of life time and other economical parameters. K. Comakli and B. Yuksel [4] also used the same method for optimizing insulation thickness in heating application. A. Bolatturk [7], O. Altan Dombayci et al. [8] also used life cycle cost analysis for getting optimum insulation thickness. Lollini et al. [9] emphasized on three level analysis means energy, economy, environment for optimizing insulation thickness for opaque components of building envelope. A. Bolatturk [12] determined optimum insulation thickness by maximizing saving over the life time. In this study P1-P2 method was used. Where P1 is the present worth factor and P2 is the ratio of life cycle investment to the initial investment. Further payback period was determined by equating net savings to zero both for heating and cooling. J. Yu et al. [16] determined the optimum insulation thickness by minimizing total cost and maximizing savings determined from P1-P2 method while cooling and heating cost was combined. A. Ucar, F. Balo [15] also determined the optimum insulation thickness by maximizing saving determined from P1-P2 method.

7. CONCLUSION

Since energy conservation is one of the important considerations throughout the world and insulation of component of envelope of conditioned building is an important strategy. But what should be the level of insulation is being discussed in this paper in terms of optimum insulation thickness. It is clear from the review of different papers in this field of research that determination of optimum insulation thickness for external wall or roof of the building has many dimensions. From climate point of view it is important to determine in advance whether the optimum insulation thickness is to be determined on the basis of cooling load or heating load thus it becomes a unique problem for a particular place. The effect of solar radiation on optimum insulation thickness is an area which needs further research in Indian context. DD or DH method is being used by many researchers for calculating annual heating cooling loads and can be used in future researches with the availability of data. It is found from literature review that there is no published result of the finding that if in place of single insulation material two insulation materials are used then what will be the outcomes.

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