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Research Paper

Environmental Impact and Life Cycle Assessment of Economically Optimized Thermal Insulation Materials for Different Climatic Region in Iraq

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Abstract

Environmental pollution is one of the biggest problems facing the world, even it is the most dangerous. Therefore, it becomes necessary to combine all efforts to reduce or eliminate it. Iraq is at the forefront of countries that suffer from major environmental problems. The present study aims to perform a comparative environmental assessment for three commonly available thermal insulation materials in Iraq namely expanded polystyrene (EPS), extruded polystyrene (XPS), and rock wool (RW) to select least environmental impact material. A cradle to gate life cycle assessment is performed to assess the environmental impact of each insulation material taking into account manufacturing, transportation, and installation and disposal stages. A life cycle assessment program SimaPro is used to model thermal insulation materials during its life cycle. A life cycle impact analysis method CML 2001 has been selected to assess the environmental aspects associated with two global damage categories as ozone layer depletion and global warming and two regional damage categories as acidification and eutrophication. Economically optimized amount of each insulation material is selected to represent the functional unit of life cycle assessment. The results illustrate that the EPS has the lower contribution in all environmental impact categories for all climatic regions. So, the EPS can be select as a proper thermal insulation material for the building sector from an economic and environmental perspective. The results of LCA are used to determine the amount of CO2 can be reduced per meter square of the exterior wall by using the economical amount of EPS during the lifetime of insulation material. The environmental impact results show that using EPS will contribute in CO_2 emission reduction at about 81.5 % in all climatic regions in Iraq.

Keywords: *Building, Economical amount of insulation material, Environmental impact, Life cycle assessment, Thermal insulation material*.

1. Introduction

Environmental pollution is one of the significant problems facing the world, even it is the most dangerous. Therefore, it becomes necessary to combine all efforts to reduce or eliminate it. Iraq is at the forefront of countries that suffer from major environmental problems. This is due to the isolation of Iraq from the world for a long time as a result of successive wars, international sanctions and the economic embargo imposed on it. The statistical information's which issued by the ministry of environment in 2013 indicates that the emissions of carbon dioxide in Iraq have increased from 52.8 million tons to 98.8 million tons over the past 20 years (Environment, 2013). That means an average of 6.6 million tons increases annually. The buildings sector in Iraq contributes significantly to the environmental problems resulting from the use of energy because this sector consumes a large proportion of locally produced electricity and most of this energy is spent for heating and cooling applications to investigate thermal comfort for occupants (Cooperation, 2009; Electricity, 2018). Therefore; the Iraqi state has resorted to the use of new policies based on scientific studies to urge citizens to rationalize the consumption of electricity in this sector.

The thermal insulation material is the best solution to reduce energy spends to heating and cooling application in buildings due to its thermo-physical properties (Bolatturk, 2008). But the important question remains at this point which is: What are the appropriate type and amount of insulation for this purpose? The sustainability can be developed in this sector if the answer to this question considered the economic and environmental aspects because they represent the main factors in the sustainability approach. Where the economic and environmental analysis can help to select appropriate thermal insulation material type and the amount which will reduce heating and cooling energy demand and ensure saving on more energy and negative environmental impacts that it consume/release throughout thermal insulation material life cycle or span. Given the importance of the subject, there are many research studies in the literature that discuss the buildings thermal insulation materials in a life-cycle perspective following many approaches. Some of these studies dealt with the economic aspect of the thermal insulating materials over its lifetime. The main aim of these studies is to determine optimum insulation thickness from an economic perspective which will provide the minimum total life-cycle cost (LCC). The economic optimum insulation thickness in these studies determined as a function of different parameters like: building type , function, orientation, constriction materials property, climatic conditions, insulation material type, insulation material type cost, energy type, energy cost, interest rate, inflation rate, lifetime, and efficiency of air-conditioning system (Bolatturk, 2008; Kaynakli, 2012; Liu, et al., 2015; Nematchoua, et al., 2015;

Wati, et al., 2015; Kurekci, 2016; Kameni Nematchoua, et al., 2017). The result of these studies helped the decision-makers in this field to determine the economic amount of different thermal insulation materials that will minimize the total LCC but did not distinguish the appropriate thermal insulation materials type which will contribute to reducing the environmental burden and also did not compute the amount of greenhouse gas emissions that can be reduce by using these materials.

In order to fill the environmental gap of economic research conducted in this subject many research studies established to study the environmental impacts of thermal insulation materials using life cycle assessment (LCA) method with the different functional unit for evaluation of environmental impact of these materials. Researchers (Papadopoulos and Giama, 2007; Zabalza Bribian, et al., 2009), analyzed the environmental impact of 1kg mass for deferent insulation materials during different stages of product life cycle. Other researchers (Schmidt, et al., 2004; Ardente, et al., 2008; Pargana, et al., 2014), studded the environmental impact and life-cycle cost of thermal insulation material amount that provide a thermal resistance value of 1m2K/W instead of 1kg mass in them LCA studies. These studies highlighted the environmental impact of deferent thermal insulation material over different environmental damage categories but 1kg mass or amount of thermal insulation material that provides thermal resistance of 1m2K/W did not represent the optimum amount of insulation from an economic perspective. For this reason, these studies have been unable to fill up the environmental gap in the economic research conducted in this subject. Furthermore, these researches have not been able to determine the amount of environmental impacts that can be reduced by applying these materials which led to a lack of awareness of the importance of these materials in improving the environmental level. So the process of building isolation did not apply in most countries where these types of studies have not been conducted such as in Iraq. The present research follows a novel methodology to illustrate the environmental benefits of thermal insulation materials in the building sector by combining the result of LCC analysis with LCA because they represent the key factors in the sustainability approach. In this research a comparative environmental assessment for three commonly available thermal insulation material in the building sector namely EPS, XPS, and RW taking the amount of thermal insulation that optimized economically for 1m2 of exterior wall area as a functional unit (base point of environmental impact comparison). The optimization analysis was done for three cities selected to represent the three different Iraqi climatic regions namely Basra city as a model of desert climate, Baghdad city as a model of semi-desert climate and Mosul city as moderate climate. The life cycle assessment software SimaPro v.7.2 (Consultants, 2013) is used to estimate the environmental impact of thermal insulation material during production, transportations, installation and disposal stages. A life cycle impact analysis method CML 2001 has been used to assess the environmental aspects associated with four damage categories as acidification (AP), eutrophication (EP), ozone layer depletion (ODP) and global warming (GWP). The result of LCA used to determine the total amount of equivalent CO2 that can be reduced per meter square of exterior wall area as a result of using the least environmental impact thermal insulation material to illustrate the importance of using thermal insulation material for decision-makers in this field. This research is expected to fill the environment gap in the economic researches conducted in this subject to incentive the Iraqi society to use the economically optimized thermal insulation to raise the environmental quality level in Iraq especially and in the world generally.

2. Methodology

2.1 Economical optimization of thermal insulation materials :

The present study is based on a previously conducted study which optimized the amount of three different types of insulation materials for a unit area of external wall in three different climatic regions in Iraq (Ameen, 2016). The amount of thermal insulation materials are optimized economically using life-cycle cost analysis (LCCA) as a function of degree-hours solar air temperature value, the efficiency of used energy, heating and cooling system coefficient of performance, wall orientation, thermal insulation cost, inflation rate and interest rate of money and surface absorption ratio. As the thermal insulation material installed one time during the construction or retrofitting process so it must take as the bigger of the two values obtained for heating and cooling application. For this reason, the optimum amount of insulation thickness for cooling is considered in this study because it is the longest and the more effective in Iraq. The optimal amount of each type of thermal insulation material that analyzed during the next stage of this study is listed in Table 1. All parameters that used in the calculation of economic optimum thermal insulation material thickness are listed in Table 2. For more information see the reference (Ameen, 2016).

Table1: Optimum thicknesses values for thermal insulation materials

Cities	Optimum thickness for EPS (m)	Optimum thickness for XPS (m)	Optimum thickness for RW (m)
Basra	0.074	0.059	0.056
Baghdad	0.064	0.052	0.048
Mosul	0.056	0.045	0.041

Table 2: All parameters used in economical optimum thermal insulation material(Ameen, 2016)

Parameters (Units)	Values		
Electricity energy cost ($/kWh)	0.05		
The coefficient of performance for the cooling system	2.5		
Thermal conductivity (W/m. ºC)	EPS	XPS	RW
	0.033	0.026	0.04
Thermal insulation cost ($/m^3)	77	95	140
Exterior wall thermal conductivity (W/m. ºC)	2.19		
Interest rate (%)	5		
Inflation rate (%)	3.5		
Lifetime (years)	10		
Cooling solar-air temperature degree-hours (ºC.h)	Basra	Baghdad	Mosul
	111015	93145	72171
heating solar-air temperature degree-hours (ºC.h)	Basra	Baghdad	Mosul
	8290	12288	16984
Inside design room temperature during cooling season (ºC)	23		
Inside design room temperature during the heating season(ºC)	18		
Density (kg/m^3)	EPS	XPS	RW
	25	32	70

2.2 Life cycle assessment:

LCA represents a powerful methodology to estimate the environmental potential impacts throughout the product's life from cradle to grave (Abusoglu and Sedeeq, 2013). LCA can help decision-makers to be able to select the product or process those results in the least impact to the environment. In this study, the LCA follows the ISO 14040 (Organization, 2006) guidelines which divide an LCA into four stages: goal and scope, inventory analysis, impact assessment and interpretation.

2.2.1 Goal and Scope: The goal and scope of this study is to evaluate the life-cycle environmental impact of economically optimize thermal insulation for unit area of external building wall in each climatic region associated with two global impact categories (ODP) and (GWP) and two regional impact categories (AP) and (EP) which are the main impact categories at the local and world level. The functional unit is defined as the amount of thermal insulation material mass in kg that needed to provide the economical optimum insulation thickness for a unit area.

2.2.2 Inventory analysis: The life cycle inventory analysis (LCI) involves collecting all data for the product described under the goal of the study. The inventory analyses are made to quantify relevant inputs and outputs in the defined life cycle system boundary. LCI represent an important stage during LCA analysis because it quantifies the amount of energy and raw materials stream flows in the boundary of the system which will ultimately determine the environmental impact of the system under study. In the present study, the boundary of the system is selected to be from cradle to grave. For the purpose of simplifying the quantifying process of the inputs and outputs to the system boundary, the life cycle of thermal insulation material is divided into many stages manufacturing, transporting and installation and disposal at the end of its lifetime. As the amount of inputs and outputs in each stage is a function to the amount of thermal insulation material so the mass of each insulation materials calculated with respect to its physical property and listed in Table 3. It is important to note that manufacturing process information is usually not very widely published (compared with the corresponding cost and other information) so the manufacturing data are taken from Ecoinvent database (Inventories, 2010). All the thermal insulation materials assumed to be manufactured in the same city and transported to the installation site using 16 tons lorry or less for a distance of 20 km. The installation process for 1m^2 area needs labor and drilling machine to make four holes in the wall which was estimated to be 10 minutes of continuous work drilling machine (2000 W). The electricity consumption for this purpose is taken from the national electric network. Iraqi electric mix is considered produce by 10% hydraulic power stations, 30% steam power plants, 60% gas power plants (Electricity, 2018). At the end of thermal insulation material life, is considered to be used in landfill.

2.2.3 Impact assessment: The inventory analysis is complete when all the necessary data is gathered. An inventory analysis consists of a long list of data and must be associated with specific environmental impact categories. This step is the life cycle impact assessment (LCIA) which can be defined as a phase in LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system, and it consists of three mandatory elements: Selection of impact categories, classification, and characterization (Organization, 2006). In this study, a life cycle impact analysis method CML 2001 has been selected to assess the environmental impact of LCI data because it is more suitable with the scope of this study. CML 2001 impact assessment method represents a powerful midpoint interpretation assessment method which classifies the inventory results to many impact categories including (AP), (EP), (ODP) and (GWP). Table 4 presents the description of the assessed impact categories selected in this study. The well-known LCA software SimaPro v.7.2 (Consultants, 2013) is used to model the thermal insulation materials throughout the LCA stages.

Table 3: Optimal amount of thermal insulation materials

Cities	The optimum amount of EPS(kg)	The optimum amount of XPS(kg)	The optimum amount of RW(kg)
Basra	1.85	1.89	3.92
Baghdad	1.63	1.66	3.36
Mosul	1.4	1.44	2.87

Table 4: Description of the environmental impact categories assessed by the CML method

Environmental Impact Categories	Description	Unit
Global Warming (GWP)	The potential contribution of a substance to the greenhouse effect.	kg CO2 equivalents (kg CO2 eq.)
Ozone Layer Depletion (ODP)	Destruction of the stratospheric ozone layer by anthropogenic emissions from a substance.	kg CFC-11 equivalents (kg CFC-11 eq.)

2.3 Environmental impact of using thermal insulation material: In order to calculate the environmental impact of thermal insulation material which is represented in this study by the amount of total equivalent CO2 reduction as a result of using economically optimized thermal insulation material during a time span of 10 years (the same lifetime used in economic analysis) is calculated by subtracting the amount of CO2 eq. produced during thermal insulation material lifespan (LCA results) from the total amount of CO2 eq. that eliminated by reducing heating and cooling energy demand.

3. Results and Discussion

The environmental impact of three different types of insulation materials is compared over its life cycle including manufacturing, transportation and installation and disposal stages in order to find out the best thermal insulation material which has a less environmental impact under operation and climatic condition of Iraq. The LCA software SimaPro is used to model the economically optimized thermal insulation materials throughout the LCA stages. Table 5 presents the environmental impact categories of three thermal insulation materials per functional unit (economically optimized thickness for a unit area of exterior wall) for three cities. The graphical comparison between insulation materials according to their environmental impact is illustrated in Figures 1-3 for each impact category after assessing the environmental impact categories referred to the three thermal insulation materials with the specified functional unit of the economical optimized amount for 1m2 area of a thermal insulation material from cradle to grave. Considering the global warming potential impact category, EPS has the lowest impact category in each city. In this impact category, the EPS performs 40% better than XPS in Basra and 48% in both Baghdad and Mosul which has the highest GWP impact in their cities. While the performance of EPS and RW is convergent in all cities in this category. Regarding Ozone Layer Depletion, EPS also has the lowest impact category in this field. But in this impact category the amount of difference is small and varies between 1 – 2% and this percentage can be ignored because of all insulation materials containing no CFCs or HCFCs which effects the ozone layers. Owing to the acidification potential impact category, RW has the highest impact in this category followed by XPS in all three cities. EPS has the lowest impact in this category too. In all cities, the EPS perform 60-62 % better than RW which has the highest GWP impact, respectively. While XPS perform 20 – 23% better than RW in all cites. In Eutrophication impact category, EPS has the lowest impact while the highest impact belongs to RW. In this impact category, EPS performs 90% better performance comparing with RW in all cities. While XPS is also perform. It becomes clear from life cycle assessment analysis regarding four impact category namely global warming potential, ozone layer depletion, acidification and eutrophication that EPS thermal insulation material at an amount of optimized economic value has the lower environmental impact with compare to the XPS and RW. Thus the economic (Ameen, 2016) and environmental analysis show that EPS thermal insulation material is the best solution to reduce the operation energy cost and life-cycle environmental impact under Iraqi operation and manufacturing conditions. Now we can calculate the amount of CO_2 eq. that can be reduced per unit area by using the economically optimized amount of EPS in each Iraqi climatic regions. As illustrated in section 2.3 the calculation done by calculating the amount of CO_2 eq. eliminated by reducing energy consumption as a result of providing thermal insulation material during the lifetime (which is taken as 10 years (Ameen, 2016)) and then subtracting the amount of CO_2 eq. produced during the life cycle of used thermal insulation material. The amount of energy reduced by using the optimal amount of EPS thermal insulation material is taken from (Ameen, 2016) and modeled in LCA software SimaPro and the result is shown in Table (6) and Fig.4.

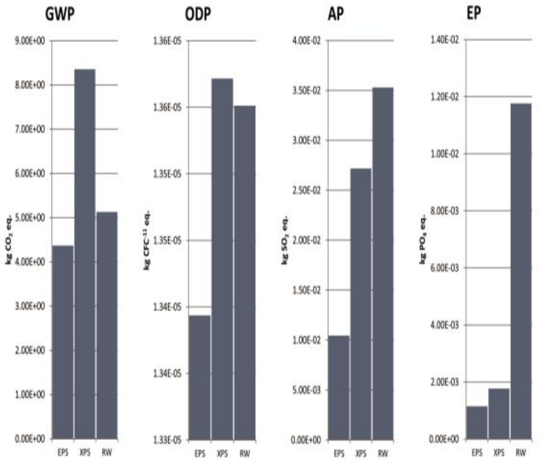

Fig. 1: Comparison of three thermal insulation materials from cradle to gate with the same functional unit (economically optimized thickness for 1m^2 wall area) for Basra city

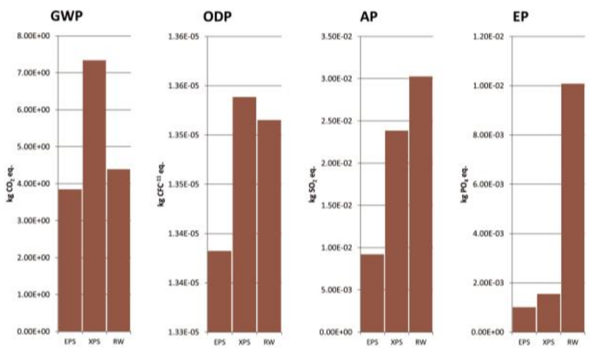

Fig. 2: Comparison of three thermal insulation materials from cradle to gate with the same functional unit (economically optimized thickness for 1m^2 wall area) for Baghdad city

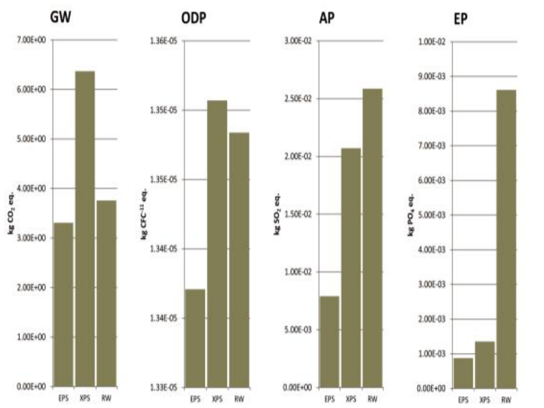

Fig. 3: Comparison of three thermal insulation materials from cradle to gate with the same functional unit (economically optimized thickness for 1m^2 wall area) for Mosul city

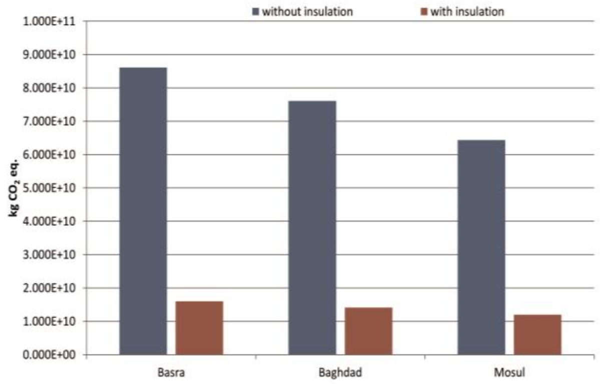

Fig. 4: Amount of CO_2 eq. per 1m^2 of the exterior wall during 10 years

Table 4: Description of the environmental impact categories assessed by the CML method

Environmental Impact Categories	Description	Unit
Global Warming (GWP)	The potential contribution of a substance to the greenhouse effect.	kg CO_2 equivalents (kg CO_2 eq.)
Ozone Layer Depletion (ODP)	Destruction of the stratospheric ozone layer by anthropogenic emissions from a substance.	kg CFC^{-11} equivalents (kg CFC^{-11} eq.)
Acidification (AP)	The increase of the acidity of water and soil by acidifying substances and processes.	kg SO_2 equivalents (kg SO_2 eq.)
Eutrophication (EP)	The increase of the concentration of nutrients, mainly Nitrogen and Phosphorus in a body of water and soil.	kg PO_4 equivalents (kg PO_4 eq.)

Table 5: Environmental impact categories referred to insulation per functional unit (economically optimized thickness for a unit area of exterior wall) for three cities

Impact Category	Unit	EPS			XPS			RW		
		Basra (1.85kg)	Baghdad (1.63kg)	Mosul (1.4kg)	Basra (1.89kg)	Baghdad (1.66kg)	Mosul (1.44kg)	Basra (3.92kg)	Baghdad (3.36)kg	Mosul (2.87kg)
GW	kg CO_2 eq.	4.37E+00	3.85E+00	3.31E+00	8.36E+00	7.34E+00	6.37E+00	5.13E+00	4.39E+00	3.75E+00
ODP	kg CFC^{-11} eq	1.34E-05	1.34E-05	1.34E-05	1.36E-05	1.35E-05	1.35E-05	1.36E-05	1.35E-05	1.35E-05
AP	kg SO_2 eq.	1.04E-02	9.21E-03	7.91E-03	2.72E-02	2.39E-02	2.07E-02	3.53E-02	3.03E-02	2.58E-02

EP	kg PO_4 eq.	1.15E-03	1.02E-03	8.73E-04	1.77E-03	1.56E-03	1.35E-03	1.18E-02	1.01E-02	8.61E-03

Table 6: Amount of CO_2 eq. for 10 years

Cities	Amount of CO_2 eq. emission without using thermal insulation material for 10 years per unit area of the exterior wall (kg CO_2 eq.)	Amount of CO_2 eq. redaction in 10 years per unit area of the exterior wall (kg CO_2 eq.)
Basra	8.614E10	7.014E10
Baghdad	7.613E10	6.198E10
Mosul	6.439E10	5.243E10

As shown from results using of EPS thermal insulation material can be reduced about 81.5% of CO_2 eq. emission in all Iraqi cities and by this way it can contribute in reducing the environmental burden in Iraq.

4. Conclusion

In this study, a comparative LCA and environmental analysis are conducted to compare three commonly available thermal insulation materials in Iraqi markets for three different climatic regions in Iraq. Economically optimized thermal insulation amount is taken as a base point of comparison (functional unit). The LCA results showed that the life cycle environmental impact of the economically optimized insulation materials is much less from the environmental impact of the energy used for heating and cooling during the lifetime because Iraq depends on 80-90% on fossil fuel in electricity production which represents the primary energy in the building sector. For this reason, using any thermal insulation material type will effectively contribute to reducing negative environmental impacts in all climatic regions in Iraq especially in Basra. But in the context of less environmental impact thermal insulation materials, the LCA results show that the EPS has the least environmental impact in all studied categories. So, the EPS thermal insulation material is the proper thermal insulation material for Iraqi buildings from an economic and environmental perspective. The using economical amount of EPS in the exterior wall can reduce the amount of CO2 emissions as about 81.5% with compare to the buildings without insulation system which represents a great amount to contribute to reducing the environmental burden in Iraq. The Iraqi government should encourage citizens to include renewable energies like solar and wind energies in the building sector as well as to use thermal insulation materials to reach the required environment quality levels in faster steps.

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