Analysis on Life-Cycle Costing for Insulated External Walls in Australia

I. M. Chethana S. Illankoon, Vivian W. Y. Tam, and Khoa N. Le

***Abstract*—Thermal insulation is one of the integral parts of building construction. Further, it is also a significant factor in achieving energy efficiency. Therefore, minimum standards are set up for thermal insulation in buildings. Further, to achieve energy efficiency of green buildings, it is required to achieve higher thermal insulation standards. The external wall being the outer skin of the building covering a considerable proportion of the building envelope, needs to be properly thermally insulated. However, there is a clear lack of research on the different types of insulation options for external walls regarding life-cycle perspective. Therefore, this research aims to develop and analyse life cycle costs for seven different types of external wall structures commonly used in Australia. Life cycle costs are calculated using net present value (NPV) technique for various types of insulation material, sarking material and different types of external wall structures in the five main cities in Australia. A sensitivity analysis is also carried out for the changes in discounting rate and for the changes in labour rates. According to the life-cycle costs analysis, the maintenance cost of the external walls varies from 13% to 29% and the costs of demolition range from 13% to 25% of life-cycle costs. Clay masonry veneer and reverse veneer external wall solutions could achieve the required minimum R-values in all climatic zones with a lower life-cycle cost. Further, life cycle cost increases with the increment of the total R-value of the external wall structure. Cost other than the initial cost varies from 34% to 45% in external walls The results derived in this research can be used to make informed decisions on insulation material selection for green buildings.**

***Index Terms*—Cost, external walls, insulation, life-cycle, total R-value.**

I. Introduction

Energy is one of the significant areas in discussion within the construction industry. Energy efficiency of a building depends on many factors. A sound thermal insulation is considered as a crucial step to reduce the energy use of buildings [1]. Therefore, proper thermal insulation is necessary for the external skin of the building including the external wall, roof and floor. According to Treloar, *et al.* [2], external walling is one of the main factors to be considered in achieving efficiency in energy consumption.

External walls are simply the outer skin of the building and defined as the vertical enclosure around the building other than windows and external door from substructure to roof including insulation to external walls but excluding internal finishes to external walls [3]. Countries with seasonal changes require better insulation to regulate the heat gains and losses. During the summer time with higher temperature, there is a requirement to minimise unwanted heat gains and vice versa during the winter.

In green building construction, a significant consideration is given to energy efficiency. Green Building Council Australia [4] identified the significance of thermal insulation for energy efficiency in green buildings and allocated credit points in the Green Star rating tool. Green Star allocates up to 5 out of 20 points for energy efficiency in green buildings focusing on thermal insulation [4]. This point allocation itself signifies the importance of thermal insulation of buildings. According to the building code of Australia, it is necessary for the buildings to achieve the minimum R-value given for each climate zone [5] as reported in Table I. Further, in green buildings, it is required to increase up to 15% of total R-value of external wall insulation compared to the national standards in Australia.

There is a wide variety of insulation material to obtain the required R-value. Further, there are many types of external walls with different insulation material and different construction methods. However, according to Rauf and Crawford [6], variations in the service life of materials can potentially lead to significant variability in a building's life cycle energy consideration. Therefore, it is necessary to select the most suited external wall structure and material considering the life-cycle costs approach. Further to that, external walls require regular maintenance which is a considerable proportion compared to the longer life-cycle of the buildings.

TABLE I: Minimum Total R-values for Different Climate Zones

Climate zone	1,2,3	4,5,6	7	8
Minimum total R-value for each part of an external wall that is part of an envelope	3.3	2.8	2.8	3.8

Considering different types of external wall structures and different material, Hasan [7], identified the optimised solutions for external walls. However, the calculation focused on the life-cycle energy savings from the various material used in wall structures and not the life-cycle cost of wall structures with different insulation material. Similarly, Gustafsson [8] identified optimised solutions for insulation in building retrofits considering life-cycle costing for building energy saving. Dombaycı, *et al.* [9] and Çomaklı and Yüksel [10] carried out similar studies to optimise external wall

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I. M. Chethana S. Illankoon and Khoa N. Le are with the School of Computing, Engineering and Mathematics, Western Sydney University, Australia (e-mail: cillankoon@gmail.com, K.Le@westernsydney.edu.au).

Vivian W. Y. Tam is with the School of Computing, Engineering and Mathematics, Western Sydney University, Australia and College of Civil Engineering, Shenzhen University, China (e-mail: vivianwytam@gmail.com).

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insulation thickness considering the life-cycle savings of energy cost. Sisman, *et al.* [11] also identified that fuel consumption and operational cost are reduced by increasing the thickness of the external walls and roof (ceiling), despite an increase in the investment costs using life-cycle cost analysis. However, in any of these cases, the life-cycle cost of the insulation material and the building components were not considered. Kaynakli [12], conducted research on determining the optimum thickness for insulation material. Kaynakli [12] adopted life-cycle costing to calculate the energy savings in the process of determining the thickness. However, this research also did not consider the life-cycle cost of the material. Vilhena, *et al.* [13], also identified an external wall covering improving the building efficiency.

Further, there are researches considering optimum solutions for different green building solutions focusing the life-cycle perspective such as heating cooling and ventilation systems [14], timber applications [15], vertical greening systems [16], optimal thermal comfort designs [17], solar panels [18], green roofs [19], roof top gardens [20], single family detached houses [21], wall material [22] and transparent insulation facades [23]. However, there is a clear lack of analysis on the life-cycle cost approach in material selection for insulation irrespective of the importance of energy considerations. Therefore, this research focuses on analysing the life-cycle costs effect on insulating the external walls to identify the optimum solutions for external wall structures for green buildings.

II. Different Types of External Walls Commonly Used in Australia

There are many types of external wall structures available. According to Insulation Council of Australia and New Zealand [24], there are eleven types of commonly used external wall structures. However, if the wall structures include specific walling solutions for factory buildings, these are excluded in this research. As an example, an external wall with metal wall claddings is identified as external walls for warehouses. Therefore, from the eleven types of external wall types, only seven types are included in this research excluding external wall structures for factory buildings and warehouses. The main types of external wall structures used in this research are reported in Table II.

According to Table II, there are different options available for lightweight cladding and internal wall lining. However, for this research fibre cement weatherboards are used for lightweight cladding, and 10mm plasterboard is used for internal wall lining. Further, external wall structure does not include any finishes as illustrated in the external wall definition given in the introduction [3]. Therefore, these structures do not account for finishing such as wall painting.

The total R-value of the external wall is the summation of all the R-values of the material forming the external wall. As an example, lightweight cladding wall (type W0200) is considered, the Total R-value would be the summation of R-values of outdoor air film, lightweight cladding, sarking material, air gap or wall insulation, 10 mm plasterboard wall lining and the indoor air film. There are main four types of sarking material available namely, vapour permeable material, single sided foils, double-sided anti-glare foils and double-sided foam foils. Additional wall insulation included wall insulation batts with varying R-values. Further, the R-value of these insulation materials depends on the thickness of the material layer also [25], [26].

TABLE II: Types of External Wall Structures
Adapted from Insulation Council of Australia and New Zealand [24]

Code	Type of external wall	Description
W0100	Clay masonry veneer	Brick veneer construction using 110 mm masonry brick, 50 mm brick cavity, 90 mm timber stud, and 10 mm plaster wall lining.
W0200	Lightweight cladding (direct fixing to stud)	Lightweight cladding fixed directly onto 90 mm timber or steel stud. Lightweight cladding includes steel sheeting, fibre cement board cladding or fibre cement weatherboard and 10 mm plaster wall lining internally.
W0300	Lightweight cladding (fixed to battens)	Lightweight cladding fixed to 35 mm battens with 90 mm timber stud frame and 10 mm plaster wall lining. Lightweight cladding includes steel sheeting (0.4 2mm), fibre cement board cladding (4.5 mm) or fibre cement weatherboard (7.5 mm).
W0800	Hollow concrete blockwork	190 mm hollow concrete block work with a 10 mm internal plasterboard lining fixed to either 40 mm battens or an adjacent 90mm stud frame.
W1000	Cavity clay masonry	Double brick wall with 50 mm brick cavity and cement render or plasterboard internal lining.
W1100	Internally insulated cavity clay masonry	Double brick wall with 50 mm cavity and without air gaps between brickwork, insulation and plasterboard internal lining. Appropriate stud dimensions should, therefore, be used to accommodate wall insulation batts. Direct fixing of plasterboard to brickwork is calculated in the case of an un-insulated wall
W1200	Reverse brick veneer	External lightweight clad wall with an interior brick leaf and plasterboard lining separated by a 50 mm cavity. The internal lining can be either direct fix plasterboard or cement render. No membrane, no battens: Lightweight cladding fixed directly on to 90mm stud with 50mm cavity behind brickwork. A 140mm air gap results in the case of no stud insulation and no membrane

III. Life-Cycle Cost Calculations for Insulated External Wall Structures

Life-cycle costs is a tool for assessing the total cost performance of an asset over time, including the acquisition, operating, maintenance, and disposal costs [27]. Australian National Audit Office [28] identified that the process of life-cycle cost fundamentally involves assessing costs arising from an asset over its life-cycle and evaluating alternatives that have an impact on this costs of ownership. According to Australian National Audit Office [28], there are five main phases which trigger different types of costs which are design, purchase and construction, operation costs, maintenance costs, development costs and disposal costs. To calculate the life-cycle costs, all these types of costs must be captured and discounted into present day values. Therefore, to calculate the life-cycle cost, net present value (NPV) calculation is used. The formula for NPV calculation is given in Equation 1.

$$\text{NPV}\ (i, N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

Equation 1: NPV calculation
Adapted from Dell'Isola and Kirk [29]

In Equation 1, *i* denotes the discount rate; t denotes the time of cash flow; *Rt* denotes the net cash flow, and *N* is the total number of periods. The discount rate is established considering the time value of money and the associated risk. It is commonly established as the minimum attractive rate of return [29]. The rate of interest on a 25-year Treasury bond in Australia is 3.25% per annum [30]. Further, the return of assets for a non-residential construction firm is around 3.30% in Australia [31]. Considering these facts, the discounting rate is identified as 3.25% for this calculation. The period for the calculation is 60 years

A. Determination of Costs

The basic initial costs are collected for the main six central business districts (CBD) of Australia, namely; Adelaide, Brisbane, Hobart, Melbourne, Perth and Sydney. All the prices are excluding Goods and Services Tax (GST) and profit. Further, Rawlinson cost database is used for cost calculations [32]. Current market prices are used for the costs developed based on the first principles. The initial cost included all material, labour and equipment cost. The initial material cost for external walls includes an insulation material, bricks or blocks as applicable, cladding, insulation membrane and the wall lining.

Each of the structures has different maintenance requirements depending on the material used. Further, the maintenance interval is also different. Table III reports the maintenance requirements used for each of the external wall structure in this research.

Productivity adjusted nominal growth of labour rate is 2.4% for all the CBDs except for Adelaide which is 2.5% [34]. Apart from that, demolition costs are also calculated. However, extra costs are added for additional care required in the demolition of material which is re-usable. The debris is assumed to be transported 15 km away from the site.

TABLE III: MAINTENANCE REQUIREMENT FOR EXTERNAL WALLS
Developed from Dell'Isola and Kirk [29]and Stanford [33]

Code	Type of maintenance	Maintenance interval	Time for maintenance (hr/m²)
W100	Repointing joints	every 15 years	0.72
W200	Minimum maintenance	every 10 years	0.18
W300	Minimum maintenance	every 10 years	0.18
W800	Repointing joints	every 15 years	0.36
W1000	Repointing joints	every 15 years	0.72
W1100	Repointing joints	every 15 years	0.72
W1200	Minimum maintenance	every 10 years	0.18

IV. ANALYSIS OF LIFE-CYCLE COSTING OF INSULATED EXTERNAL WALLS

Life-cycle cost is calculated for each CBD and each external wall type. Table IV represents life cycle costs for clay masonry veneer (Type W0100) in Sydney area

According to the facts presented in Table IV when the insulation is higher the life- cycle cost tends to increase. The highest life-cycle cost value is recorded for wall structure with wall batts R2.5 and with sarking material using Double-sided bubble/foam foil. Further, this wall structure has the highest Total R-values as well.

As illustrated in previous sections, life-cycle cost is calculated for all the external wall types in all the CBDs in Australia. According to the results, lightweight cladding walls fixed to timber studs and battens (type W0200 and W0300) have the lowest life-cycle cost in all the CBDs. Further, an internally insulated cavity clay masonry external wall (type W1100) has the highest life-cycle cost.

After calculating the life-cycle cost for each external wall type a detailed analysis is carried out on the changes on sarking material, changes to the insulation material while other factors held constant. Further a comparison for each type of costs that is maintenance cost, initial cost and demolition cost is also carried out. Fig. 1, provides a graph comparing each type of costs for wall structures with insulation material with R-value of 1.5 and without any sarking.

TABLE IV: LIFE-CYCLE COST FOR CLAY MASONRY VENEER (TYPE W0100) WALL TYPE IN SYDNEY

Type of insulation	Vapour permeable membrane		Single-sided foil		Double-sided anti-glare foil		Double-sided bubble/Foam foil	
	Total R-value	Life cycle cost (AUD/m²)	Total R-value	Life cycle cost (AUD/m²)	Total R-value	Life cycle cost (AUD/m²)	Total R-value	Life cycle cost (AUD/m²)
Air gap (90 mm)	0.76	380.20	1.3	386.65	1.8	379.05	1.9	387.05
Stud wall batts R1.5	2.2	390.80	2.2	397.25	2.7	389.65	2.9	397.65
Stud wall batts R2.0	2.7	391.20	2.7	397.65	3.3	390.05	3.5	398.05
Stud wall batts R2.5	3.2	391.90	3.2	398.35	3.8	390.75	4.0	398.75

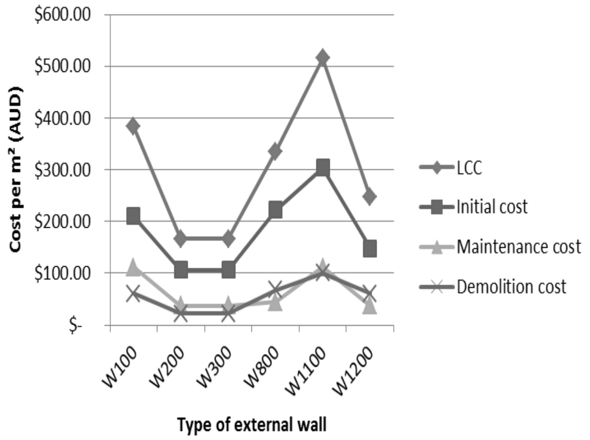

Fig. 1. Cost comparison for different types of external walls.

According to Fig. 1, irrespective of the type of external wall, initial costs contribute to the highest proportion of the life-cycle cost. However, maintenance costs and demolition costs have contributed to almost similar proportion to the life-cycle cost. In hollow concrete block wall (type W0800) and reverse brick veneer (type W1200), the demolition cost is slightly higher than that of the cost of maintenance. Further, the maintenance cost of these types of external wall in Sydney ranges from 13% to 29% of the life- cycle costs. The cost of demolition varies from 13% to 25% of the life- cycle costs. Table V below illustrates the maintenance and demolition costs as a proportion of the life-cycle cost and initial cost.

TABLE V: MAINTENANCE AND DEMOLITION COSTS FOR DIFFERENT TYPES OF WALLS

Type of wall	As a % of life-cycle cost		As a % of initial cost	
	Maintenance cost	Demolition cost	Maintena nce cost	Demolition cost
W0100	29%	16%	53%	29%
W0200	23%	13%	35%	21%
W0300	23%	13%	35%	21%
W0800	13%	20%	20%	30%
W1100	22%	20%	37%	33%
W1200	15%	25%	25%	41%

According to the Table V, the maintenance costs varies from 20% to 53% as a proportion of the initial costs and the demolition costs ranges from 21% to 41% of the initial costs. The life-cycle cost other than initial cost ranges from 34% to 45% in external walls.

A. Sensitivity Analysis

As illustrated in the literature, after the life- cycle cost calculation a sensitivity analysis is carried out. Sensitivity is calculated to the changes in the discounting rate and the labour rates. The sensitivity to the discounting rate is calculated by reducing the discounting rate by 1.5% and increasing by 1.5%. The results are given as illustrated in Fig. 2 below. Further, the labour market is rather a volatile market in the construction industry. Therefore, the effects on the life-cycle cost of the external wall types to the changes in labour rates are also calculated.

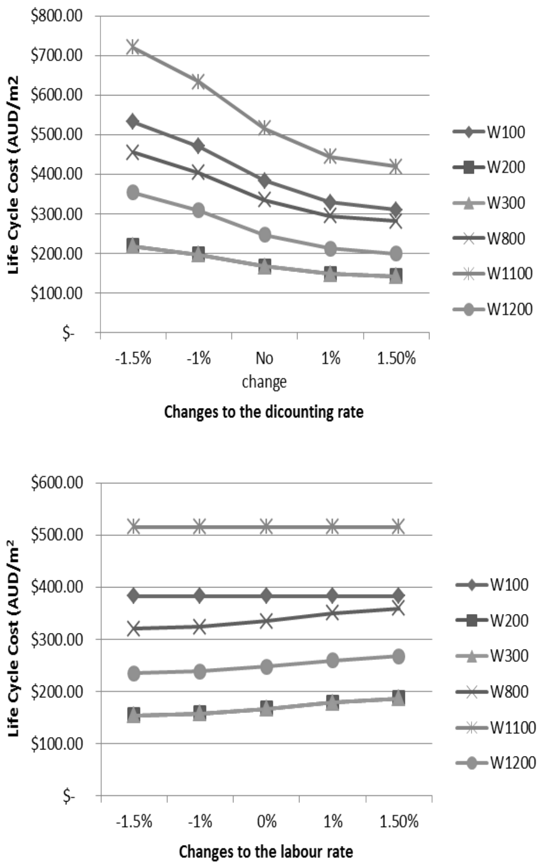

Fig. 2. Sensitivity to the changes in discounting rate and labour rates.

The discounting rate change comparatively affects all the external wall types. However, when the discounting rate is lower, there are significant increases in the life- cycle costs. When considering the changes in life cycle cost to the changes in labour rate, hollow concrete block wall (type W0800) has significant changes to the increase in labour rates. Further, there is slight increase in life-cycle cost to the increase in labour rates for reverse brick veneer (type W1200), lightweight cladding wall fixed to cladding (type W300) and lightweight cladding wall fixed to battens (typeW200). The main reason for the increment of the life-cycle cost is the time spent on maintenance and demolition. Compared to other wall types, hollow block wall (type W0800) requires slightly higher maintenance and higher costs for demolition. This is identified as the main reason for the higher sensitivity to labour rate changes.

V. CONCLUSION

This research identified the insulation requirements for external walls structures in Australia and calculated the life-cycle cost for each of these structures. Initially, this research identified seven types of external walls, and for these different types of external wall structures, the various insulation material is considered to obtain the required R-values. Current prices for calculating the costs were collected from six main CBDs of Australia. Therefore, due to the changes in prices, life cycle cost is calculated for the six main CBDs separately. The life-cycle cost is calculated using the NPV techniques. Life-cycle cost calculation considered all the life-cycle cost including initial cost, maintenance cost, replacement cost and disposal cost.

The initial cost of the wall structure changes to the insulation material used. Higher the R-value the life-cycle cost is higher. Further, if the external face of the external wall has a brick wall, cost of demolition slightly increases because extra care required during the demolition as bricks can be re-used. Therefore, the additional cost is included for handling, maintaining and stacking and setting aside for reusing. Usually, the cost of maintenance for insulated external walls varies from 13% to 29% of the life cycle cost. Further, the cost of demolition ranges from 13% to 25% of the life-cycle cost. The life-cycle cost other than initial cost ranges from 34% to 45% in external walls.

Discounting rates and labour rates have an impact towards the life-cycle cost of external wall structures. The sensitivity analysis illustrates that the life-cycle cost significantly increases to a decrease in discounting rate. However, the changes in discounting rate have a significant impact on the life-cycle cost.

In this research, only the life cycle cost for external walls with insulation is calculated. However, there are direct energy savings with the changes in the thermal insulation which is not included in this research. Therefore, further research can be carried out even focusing on the impact of energy in the life-cycle cost for structures with necessary insulation. This life- cycle cost data can be used by the construction managers to derive informed decision making in material selection for green buildings at the initial stages of the studies.

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I. M. Chethana S. Illankoon is a Ph.D candidate at Western Sydney University, Australia. She did her bachelor's degree in quantity surveying from University of Moratuwa Sri Lanka. She is a graduate member of Institute of Quantity Surveyors Sri Lanka. Her research interests include sustainable construction

and green buildings, procurement, life-cycle costing and claims management in construction.

Vivian W. Y. Tam is the director of research quality and innovation and director of higher degree research student excellence at School of Computing, Engineering and Mathematics, Western Sydney University, Australia and honorary professor at College of Civil Engineering, Shenzhen University, China. She received her Ph.D in sustainable construction from the Department of Building and Construction at City University of Hong Kong in 2005. Her research interests are in the areas of environmental management in construction and sustainable development. She is currently the editor of International Journal of Construction Management and the Research Group Leader for Sustainable Construction Management and Education Research Group under the School. She has published over 3 books, 19 book chapters, 196 referred journal articles and 91 referred conference articles. She has been awarded thirty-one research grants (totalled AU$2.1 million), including the first of two Australian Research Council (ARC) Discovery Projects, awarded under FoR 1202 (Building).

Khoa N. Le received his Ph.D in October 2002 from Monash University, Melbourne, Australia. From April 2003 to June 2009, He was a lecturer at Griffith University, Gold Coast campus, Griffith School of Engineering. From January to July 2008, he was a visiting professor at Intelligence Signal Processing Laboratory, Korea University, Seoul, Korea. From January 2009 to February 2009, he was a visiting professor at the Wireless Communication Centre, University Technology Malaysia, Johor Bahru, Malaysia. He is currently a senior lecturer at School of Computing, Engineering and Mathematics, University of Western Sydney. His research interests are in wireless communications with applications to structural problems, image processing and wavelet theory. Le is the editor in chief of International Journal of Ad hoc, Sensor & Ubiquitous Computing (IJASUC). He has also been on the editorial board of International Research Magazine of Computer Science and other wireless communications journals.

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