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Life Cycle Energy Analysis comparison between retrofitting and rebuilding: case of George Green Library

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Abstract

The research is looking into materials use in retrofitting building or rebuilding and to understanding their impact on the overall energy consumption by using LCEA method. The aim of this research is to analyse and compare LCE of retrofitted part and new extension of the George Green library building with focus on energy use and other alternatives. As both buildings are designed to operate in compliance with Part L regulations, we examined their performance in term of embodied, recurring, demolition, recycling and reuse energy in their LC. The retrofitted scenario showed lower energy overall compare to new building though both have similar materials. Most materials from the old building have high recycled value which has contributed to lower its total energy. Both have high recycling value at the end building life, but the rebuilding case has more than 80% more embodied energy. More research in LCA is required to lower building embodied energy and improve further its energy consumption using recycled materials.

Key words: Building retrofit, life cycle energy analysis (LCEA), building, rebuilding, embodied energy

Introduction

The utilisation of energy in buildings and construction sector has drawn of great concern since studies have shown that building industry worldwide is responsible for 30% to 40% energy and emitting around 40% CO2 (Change, 28th March 2013), major cause of global warming. The analysis of construction industry shows that large number of building is getting added every year for different purpose worldwide. Since they consume large energy during their life cycle (LC), it has therefore become important and imperative to develop buildings with low environmental impacts. From early 70's efforts have been underway to evaluate buildings environmental impact using life cycle analyse (LCA) tool that assess buildings sustainability before actual construction could take place. The inventory tool assesses direct and indirect energy input in all building phase of life; (excavation, production, construction, operation and maintenance and finally demolition) through a life cycle energy analysis (LCEA). In this way environmental impact of buildings energy input life cycle energy (LCE) are evaluated while comparing different materials energy content in construction (embodied energy), and also the relationship between energy input in phases(e.g. embodied and operational). In the UK a large stock of building already exist but inadequate for latest energy regulation consumption in building, the tool can help estimate the energy impact of maintaining old structure by refurbishment or

replacement with totally new building. The energy impact of retrofitting has been largely discussed in many research papers looking at operational potential of energy reduction. Like studies of conventional office buildings have shown that operational energy is always higher than embodied energy; it is varying between 70% and 90% of building LCE. (Hestnes, 2006). The energy in operation can be reduced by introducing energy efficient measure and according to studies energy efficient buildings consume 40% less energy than ordinary buildings. (Yu Huang, 2013). The reduction of operational energy is achieved at the cost of increase in embodied energy (Thormark, 2002), the results show that embodied energy in the case of low energy buildings can contribute between 40% to 60% of LCE unlike 10% to 20% like the case of high operational energy buildings. Having said this, it means that energy efficient in retrofitted buildings will surely need extra materials and therefore require additional embodied energy. According to another study of commercial building, energy savings in operation of efficient retrofitting are approximately 69% to 92% depending on the building requirement (Knaackb, 2013). Looking at the total scenario in the UK, it is clear that old buildings are there to stay and solution bring them to required efficiency and cut down high energy consumption efficient buildings and energy reduction, in one hand buildings stock already built is considerably high and in the other, energy savings achievement of retrofitted building pave clearly the way forward for maintaining them through an extensive retrofitting program. The question will be, how much more materials hence embodied energy will be required to achieve high efficiency retrofitting and can it be comparable to that of new buildings.

Aims and Scope of study

Retrofitting of public buildings have not been much covered and so far research in this regards has been limited to energy in operations and users comfort though the problem of sustainability rely also in how buildings are constructed. Hence the study aims to present an institutional building, George Green Library (GGL) retrofitting case with special focus on embodied energy comparison in LCE of both refurbishment and rebuilding. Though studies have shown that improving efficient have repercussion on embodied energy and more true in retrofitting case where envelope needs high insulation, double glazing etc to lower energy demand. The same goes with new buildings with high efficiency like the rebuilding of GGL and the extension one as two different buildings and their respective LCE compared. Finally an economic evaluation of the refurbishment against rebuilding was carried from of LCE savings. At the end of the study, we hope to demonstrate from results that energy in materials from retrofitting is lower than of rebuilding and further that rebuilding operation savings are not as important as embodied energy in LCE. We will show that retrofitting is a better approach to save energy not only in operation but in materials as well, and rebuilding old structure provides solution for operations only. Our study is based on retrofitting case of George Green Library in the Nottingham University Park campus. The library is a1970's construction and best case for retrofitting as it is not responding to latest changes in building regulations on energy consumption and the university wish to have much larger space for shelving and users. The study looked into embodied energy of new materials used in retrofitting and extension building.

Literature review

Life cycle energy analysis is defined as a method of determining the real energy used in materials (in this case, building materials) throughout the life of the products starting from its cradle and ending with its demolition. It analyses the environmental impact of the building in reference to energy consumed during its life span. Building life cycle energy requires a thorough analysis of energy consumption at different

phases of building lifespan. It is estimated that average life of office building in UK is between 15-20 years, and representing 7% of the total embodied energy consumed by materials (Smith, 2001). In general a building life time comes to an end when its negatives effects become dominant over the positives. Like when it energy consumption is increasingly higher with time or the structure is no more sound enough to withstand its load. But this time is very uncertain as it grows with both positives and negatives effects on the building during its living period. In some cases the decay or degradation can be delayed or slowed by renovating the building and giving it new life for another period time. A study in Australia residential building has confirmed other figures which say that embodied energy contributes 30% of total life cycle energy consumption (Haynes, 2010) . He also suggested that recycle and reuse of materials at the end of building life cycle can have an enormous impact on the total energy consumption. B. Rossello-Batle et al. carried out LCA of hotels in the Balearic Islands and presented building processes which have maximum impact during 50 years life time (Beatriz Rossello-Batle, 2010). In all three cases concrete forms the structure of the building and contributes around 45% to 50% of the total mass when the installation has just 1.5%, very negligible participation. They also observed that total operational energy over 50 years period is 78% of the total energy use and construction phase is barely 1/5 of that value. Further they suggest that almost 97% of energy in construction phase is in the form of embodied energy in materials. In another research on life cycle energy of building by Ramesh T. et al. demonstrate after studying more than 73 buildings of different functions in 13 countries with variety of climates (Ramesh, 2010). They came to a conclusion like others that embodied account only of 10% or 20% (and the operational account of the rest 80%-90%). Study of materials impact in low energy buildings reveal that embodied energy of these buildings account for 40% to 60% of total energy as result of increased insulation (Thormark, 2002). Further the study said that about 37% to 42% of the embodied energy can be recovered by recycling which has a potential of 15% of the total energy over 50 years life cycle. In another paper related to material choice effect (Thormark, 2006) ; results showed that energy per SQM of floor area can be reduced by 10% to 15% through recycling and reuse. The analysis of building materials (Jagadish, 2001)shows that a reinforced concrete multi-storey house embodied energy is around 8- 10GJ/SQM, whereas that of wooden structure is 3GJ/SQM. They concluded that construction with energy efficient alternative technologies can decrease to great extend building embodied energy (45% to 62%), after a comparison of concrete framed structure and load bearing brick structure. In another comparison of materials, he claims that glass and aluminium cladding buildings have embodied energy varying between 5 and 10GJ/SQM (Reddy, 2009). The impacts of construction technologies also was analysed by (Kernan, 1996) and concluded that commercial buildings with steel framed structure have highest impact compare to concrete and wood and distributes as 67, 61 and 41 respectively. Another study (J. Basbagill, 2013) analysed impacts of building components and showed that all components can have potential to increase embodied energy unless the choice is more toward materials with low embodied energy index. The study concluded saying that component from structure and envelope have more than 40%, highest impact and this can be reduced to a fifth depending on materials. They further claim that potential of reducing embodied energy impact before decision on materials and thickness is between 63% and 75% depending on design parameters.

Results and discussions

Retrofitting savings from reuse and recycling

The retrofitted building had retained structural frame along with concrete wall from the existing GGL, resulting in a saving opportunity of 233.4GJ of energy from concrete and steel bars. This represented 83.9% of the whole energy required in demolition and approximately 3% of embodied energy of materials. As already observed earlier, demolition is 14% of recycling energy.

Comparison of embodied energy savings

A comparison of both buildings initial embodied energy was carried out and the result shows that the rebuilding embodied energy is 99 time that of retrofitting and with 430474.9GJ (figure1). A more specific look at the material embodied energy shows that retrofitted building materials are having almost same range of energy values, which shows a balance between materials with high and low energy index. This combination of materials in design was proposed by many studies as good solution for controlling embodied energy **(Haynes, 2010) (Thormark, 2006)**. It means that low energy index materials are in greater quantity than those with high energy index. The quantities of materials was also analysed and it shows that steel in retrofit is 36% (2106GJ) whereas in rebuilding it is 62% (268061.3GJ), and cement is absent from the first case but occupy 33% (148651.2GJ) in the second. The embodied energy difference in steel alone is 265955.3GJ, 12628.62% more than all steel used in retrofit work. These figures in rebuilding are matching previous study on structural steel and concrete mixed building in which embodied energy of steel construction was between 42%-72% and that of concrete 18%-35% **(Kernan, 1996)**.

Rebuilding energy repartition by phase in LC

The analysis of LCE shows that embodied energy is the most important phase with approximately 93% of the total and contributing 430474.9GJ for a total LC energy of 463793.2GJ. This represents 113.7GJ/M² of energy in 50 years life of the building when operational energy represents just 7.2% of and recurring energy is almost not present at 0.01% and 60.1GJ.

Significance of Embodied energy in Rebuilding

The dominance of embodied over operational has come from extensive use of steel, concrete, glass and aluminium as main material for the building construction and the absence of partitions. This scenario is the exact opposite of what we observed in the retrofitting case but concord with research on energy efficient buildings (Reddy, 2009) (Hestnes, 2006). They studies showed that to achieved low carbon buildings the embodied energy tends to increase. But in this case we should note that the embodied energy 10 times more than 10GJ/M² figure in the studies. To achieve results from previous studies steel, concrete and aluminium had to be cut down below 15% from their actual quantities.

Significance of recycled materials

Another analysis of embodied energy in rebuilding using recycled materials has shown great savings estimated at 40% and representing 173090.9GJ. The decrease in embodied energy realise when replacing virgin materials with recycled has confirmed previous work where the figure was around 37% to 42% during 50 years life time (Thormark, 2002).

Comparison of embodied energy in all cases

The result shows clearly that the retrofitting case has the least initial embodied even when compared to rebuilding with totally recycled steel and aluminium materials. Though the recycled materials case has reduced considerably initial embodied energy, 42% reduction from the initial case of virgin materials. It has still remained very high at approximately 97% against 2.31% of retrofitting case. The reduction realised from virgin materials case to recycle has just weigh 1% if compared to retrofitting case. These results is purely because on the fact steel and aluminium input in the retrofitting building is very minimal compared to the other two cases which design is depending on these materials.

Economic evaluation of energy savings

The analysis of saving from operation in retrofit shows a net difference of 1148.35 representing 36.14% of potential energy saving from electricity and resulting in monetary savings of 18258.8£ yearly. After 50 years it resulted to a surprising energy saving of 912938.65£. It also has been observed that saving are around 63% over the LC and this figure is accepted by most retrofitted research work (Dr. A. Stafford, 2011). The same was calculated with energy increased rate of 10% every 10years and results have been quite astonishing with approximately 96.44% saving and resulting in a decrease from 15770176.31£ to 561277.6509£ recording a net saving difference of 15208898.66£ in the life time of 50years.

Evaluation of reusing all structure

We further analysed embodied energy saving provided to retrofitting from reusing the old structure and it saves around 842.6M³ of concrete and 22.6M³ of reinforced steel bars. These two materials have together an accumulating embodied energy of 6599.647.9GJ and representing a monetary saving in the order of 104934.40£ in the refurbished building.

Evaluation of retrofitting and rebuilding (Virgin materials)

The analysis of retrofitting building presents an embodied energy of 58025.299GJ against 430474.85GJ for rebuilding. The difference in initial embodied energy shows a saving of 372449.5564GJ in the retrofitting building which converted to the value of energy represents an approximate 5921947.947£. This saving value is 46 times more the amount invested in the embodied energy of the retrofitting building without including the structural element.

Evaluation of retrofitting and rebuilding (recycled materials)

This last case of economic evaluation has compared the possibility of embodied energy savings from recycled materials in comparison with that of retrofitting earlier discussed. The calculations of energy have revealed a decrease of 42.2% from virgin materials and net energy saving of 245508.51GJ in 50 years. Applying the same energy rate as earlier the saving is estimated to £3903585.24 which represents 42 times the money spent in making the retrofitting materials.

Conclusion and recommendations

In this study an attempt was made to

- Show the impact of embodied energy in GGL retrofitting and new extension in the building LC
- Compare the embodied energy impact of both buildings
- Evaluate energy savings between both designs and use alternative materials

In first case the reuse of existing structural frame had made the biggest impact in energy decrease when in the other the new structural and envelope increased very considerably embodied energy impact on the building. In both case the operational energy was lower than embodied energy and this was more enhanced in the rebuilding option.an attempt was made too reducing embodied energy in rebuilding case by introducing recycled materials, the reduction was very considerable but still above that of retrofitting. Energy in rebuilding most concentrated in structure and envelope because the interior contribution is only from flooring. The construction is based on steel, aluminium, glass and concrete due to time constraint and quick execution as these can be assembled on site. And these materials have very high recycling value at end life, around 85% for steel and aluminium and more than 70% to 80% for concrete reducing embodied energy of next construction (MacSporran C.1994). We think that retrofitting should be given priority and LCE analysis done before considering rebuilding and used of recycled products should introduced in the production of new materials, also direct reuse encouraged by designers and policy makers.

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