IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Towards a holistic energy analysis of buildings- the Life Cycle Analysis way

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***Abstract*:**

World over, the issue of reduction of energy consumption in the buildings has become the most burning issue and the last decade has seen a substantial quantum of efforts towards reducing the same. However, the primary focus in most of these efforts has been on operational energy, with lesser weightage given to the other forms of energy. A holistic approach towards computing energy efficiency, covering all the energy consumption phases has been by and large missing both at the international as well as the national level. The primary research work done in this paper pertains to the establishment of such a wholesome approach by adopting Life Cycle Energy Analysis as a means to assess energy consumption. The paper lays down the methodology for the same to be broadly consisting of consolidating the existing data, evolving scientific parameters for computation of embodied energy, establishing standard processes for calculating LCEA, comparing the results with the work done by other research organizations and refining the same. Finally, the paper seeks to implement the results of the studies by putting in place uniform methodologies and systems for computing LCEA with respect to Indian conditions, substituting the present energy assessment systems with LCEA, and incorporating the same in the major rating systems including GRIHA and LEEDS.

I. INTRODUCTION

Objectives of the paper: To

- Demonstrate the importance of the different forms of energy that are consumed during a building's life time
- Establish interrelationship between these
- Briefly explain Life Cycle Energy Analysis (LCEA), its' commonly understood components and methodology
- Build up a case for reviving the use of LCEA for the overall energy assessment of a building
- Explore the obstacles in implementing LCEA
- Suggest means of overcoming these obstacles so as to achieve a holistic means of assessment of energy consumption by buildings

II. FORMS OF ENERGY ASSOCIATED WITH A BUILDING

It is a well-established fact that there are different forms of energy consumed during the entire life span of the building, which essentially means the energy expended by the building from " Cradle" to " Cradle", i.e. the energy consumed by the building in its entire life cycle, starting from the extraction of the building material (Cradle) from Mother Earth to the recycling of the building material post demolition , back to Cradle[1].Based on the above explanation, the different forms of energy used during the life span of a building can be broadly classified into the following categories[2]:

- *Embodied energy comprising of energy consumed in:*
  - Extraction of raw materials
  - Manufacture of basic building materials/components
  - Transportation of the above to construction site
  - Construction of the building
- *Operational Energy comprising of energy consumed in:*
  - Building Usage
  - Repair & maintenance of the building
  - Energy consumed in the demolition and reuse of building materials/components

There are varying opinions in respect of the above-mentioned break up. As per one school of thought, energy used in transportation is small in magnitude and should be excluded from the Embodied energy calculations. However, this argument is invalid where the materials / components need to be brought to the site from a considerable distance.

There is also a school of thought which says that the energy consumed in the demolition and reuse of building materials/components should not be a part of the operational energy and should be assessed separately. For the purpose of this paper, however, I have included it within operational energy. Notwithstanding these minor differences of definitions, one needs to look at the essence of the subject and understand the inter relationship between the different forms of energy.

III. ESTABLISHING AN INTERRELATIONSHIP BETWEEN EMBODIED AND OPERATIONAL ENERGY:

A. Case Study 1: A house in rural North India [2]:

This case study was reviewed because it represents a large quantum of the rural housing stock in the country which is constructed largely out of different forms of earth construction due to reasons of affordability. However, brick masonry is gradually replacing earth construction. Similarly, fiber-cement tiles are increasingly replacing G.I sheets for roofing. All these materials have been taken into account for the analysis. A large percentage of our rural housing stock does not have access to electricity. Day time cooling is provided through passive measures. For night time heating in winters, the cooking challah provides the additional energy besides energy from the thermal storage measures [2].

Table- I: Project details of Case Study 1

Parameter	Data
Area	1100 sft
Building Program	A living room, two bed rooms. Kitchen, verandah, Courtyard
Building Type	Rural house
Members involved in LCEA	Architect, Energy Modeler
Functional Unit:	Impacts have been calculated on a per square foot basis.
Building Lifespan:	A 40-year lifespan was estimated by the architect.
Environmental Features	Earth Masonry as thermal mass Courtyard as heat sink
System Boundary	The life cycle of the project was divided into two phases: a) Material production &Construction and b) Operations
Specifications	Brick/ Earth Masonry G.I / fiber-cement tiles sheets for roofing Timber joinery

- *Results from the study:*
  - The total embodied energy in this house is estimated to be about 100 MJ. However, if bricks are replaced with earth for masonry, and G.I sheet with fiber-cement tiles, the embodied energy for the house can be brought down to as little as 20 MJ [2].
  - Many rural households still use firewood for cooking and do not have electricity. The firewood also keeps the space warm at night. Based on the average user pattern, the primary annual energy requirement can be taken as 24MJ, which pertains to the energy from firewood. Most of this energy will be used for cooking. However, we can consider 30 % of this energy to be used for space heating, which comes to 7.2 MJ of annual energy [2].

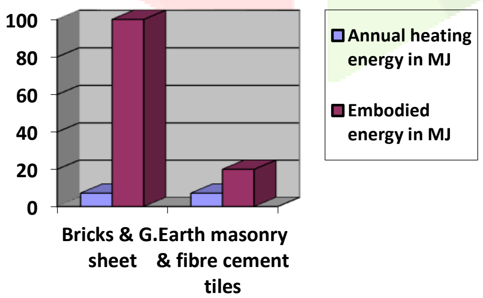

Fig. 1.Comparison of Annual heating energy and Embodied energy for a house in rural North India

- *Major Inferences from the study*
  - Embodied energy constitutes about fourteen times annual heating energy if the house is built with brick and G.I sheets, but only three times annual heating energy if it is made with low energy local materials [2].
  - For buildings with low embodied energy such as earthen houses in rural India, which are still in abundance, the ratio between annual operational energy and embodied energy is much smaller as compared to buildings with high embodied energy.
  - In this particular case, it is advisable to reduce the embodied energy since the building is entirely dependent on passive measures for thermal control and does not rely on electricity or mechanical means of heating or cooling. Paradoxical as it may sound, this does not hold good for a' pucca' construction using electricity and relying on mechanical means for cooling and heating, even if partially so.

Table- II: Results & Inferences of Case Study 1

Input	Result/Inference
Bricks replaced with earth for masonry, and G.I sheet with fiber-cement tiles for roofing	Embodied energy brought down to 20MJ from 100 MJ
Use of bricks for masonry and G.I sheets for roofing	Embodied energy comes to about fourteen times the annual heating energy
Bricks replaced with earth for masonry, and G.I sheet with fiber-cement tiles for roofing	Embodied energy comes to about three times the annual heating energy
Use of materials with low embodied energy	The ratio between annual operational energy and embodied energy is much smaller as compared to buildings with high embodied energy materials.

B. Case Study 2: NJMC Centre for Environmental and Scientific Education, NJ, US [1] [7]:

This case study is a very good documented example of applying LCEA to an entire building.

Table- III: Project details of Case Study 2

Parameter	Data
Area	9,590 sft
Building Program	3 Classrooms, a Classroom/Laboratory, a Wet Chemistry Laboratory, Administrative Offices, along with an Observatory
Building Type	Educational Facility
Members involved in LCEA	LCEA Expert, General Contractor, Product Vendor/Manufacturer, Architect, Owner, Energy Modeler
Functional Unit:	Built up area in square foot has been considered as the functional unit and the energy impact has been calculated taking this unit as the bases
Building Lifespan:	The study has taken into account a 50 year lifespan. However, it the study has also explored the difference in the results for a 75 year lifespan.
Environmental Features	Solar panels on the roof top Ceiling solar tubes Recycled building materials Recyclable and locally manufactured standing-seam metal roof Energy-efficient heating,ventilation, lighting, and water supply system
Break up of the Life cycle into phases	The life cycle of the project was divided into three phases: Material Placement, Operation, and Decommissioning.
Specifications	• Timber beams and columns along with concrete masonry units. • 150mm x 50 mm timber studs with glass fibre and insulation, cladded with gypsum board for the external wall • Cast-in-situ concrete floor slab • Pitched roofs with north-facing clerestory windows. • High-performance glass in the windows • Aluminum-cladded timber and performance glass for external doors

- *Results from the study:*
  - Compared to a conventional educational building, the NJMC building has a much lesser environmental impact due to the reduced overall energy consumption [7].
  - However, the NJMC building has much higher energy consumption in the material placement phase compared to the conventional building, and a significantly lower energy consumption in the operation phase compared to the conventional building, mainly on account of the quantity as well as quality of the materials. An increase in the quantity of the materials leads to an increase in the embodied energy. Similarly, energy intensive materials used in the NJMC building such as photovoltaic cells, concrete foundation caps and floor slab, roof decking, and standing seam metal roof have also contributed to the higher values of embodied energy [1][7].
  - On account of some of the materials such as photovoltaic cells, roof decking, external insulation etc., lesser amount of energy gets consumed in the decommissioning phase compared to the material placement and the operations phases. Figure 2 shows the distribution of the energy impacts among the different life cycle phases of the NJMC building. The Y-axis indicates the energy used during each life cycle stage as a percentage of the overall energy consumed [1][7].
- *Major Inferences from the study:*
  - The first important inference from the study is that the selection of high energy materials during the material placement phase leads to significant and unexpected energy reductions in the operations phase [1].
  - Materials considered as "low energy" i.e.-low embodied energy can lead to high operational energy. Therefore, in the overall scenario, it cannot be generalized that a low energy material will necessarily lead to overall energy reductions in a building. Often the "Low energy" materials will have a large environmental footprint, as shown by this study. On the contrary, it is also possible that a low energy building may achieve a much lesser overall energy footprint as compared to a so called "zero energy "building, as enumerated in IV below [1].
  - The estimated life span of a building is a major factor in deciding which life cycle phase needs more attention- the extraction, manufacturing and construction phase or the operation and maintenance phase.

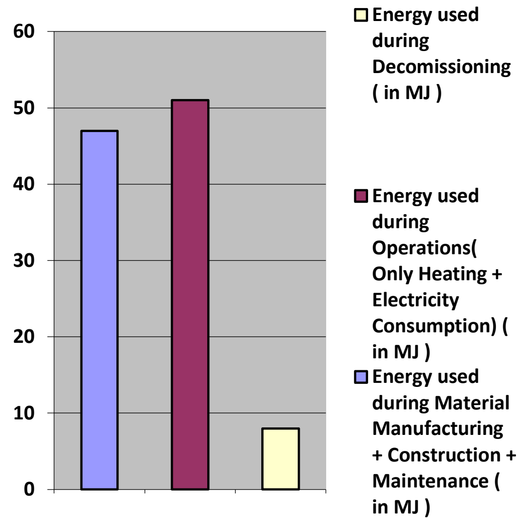

Fig. 2 Comparison of the different forms of energy during the building's life span for NJMC Centre for Environmental and Scientific Education, NJ, US

Table- III: Results & Inferences of Case Study 2

Input	Result/Inference
Increase in the quantity of the materials	Increase in the Embodied energy, reduction in Operational energy
Use of high embodied energy materials	Increase in the Embodied energy, reduction in Operational energy
Use of high embodied energy materials	Reduction in energy consumption during De-comissioning phase
Use of low embodied energy materials	Large environmental footprint, due to high operational energy

C. Case Study 3: A house in a warm temperate climate [2]:

This study shows that it is possible to have a tradeoff between embodied energy and annual 66operational energy consumption on account of modifications to exiting or projected buildings. Since the results are applicable to a wide range of projects, it is not required to specify the project details.

Table- IV: Trade−offs between energy costs and energy saving of insulation (after Stein)

Wall type	Energy requirement		Payback period (Months)
	Annual energy requirement (MJ)	Embodied energy (MJ)	
Wood shingles:			
No insulation	30.7	26.5	
90 mm insulation	9.45	33.76	
Difference	21.25	7.26	4
Brick cladding			
No insulation	29.4	153.0	
90 mm insulation	9.33	160.4	
Difference	20.07	7.40	4.5

- *Results from the study:*
  - The effect of adding insulation to two of the walling assemblies shown in table given above has been calculated. The additional embodied energy can be compared with the annual energy savings [2].

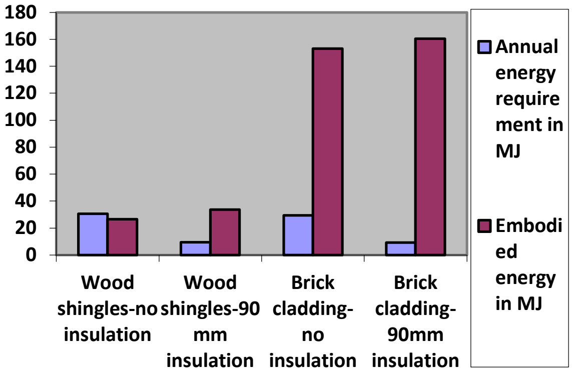

Fig. 2. Comparison between Annual energy and Embodied energy by changing the walling materials for a house in a warm temperate climate.

- *Major Inferences from the study:*
  - Taking typical data for a warm temperate climate, it can be inferred that for an increase in embodied energy in the house as a whole of 7.26 MJ, an annual saving of 21.25 MJ can be made, i.e., there is a payback period in energy terms of about four months [2].
  - It is therefore possible to have a trade-off between the embodied energy and the annual energy by changing the specifications.

Table- V: Results & Inferences of Case Study 3

Input	**Result/Inference**
No insulaion	High annual energy and medium embodied energy
Addition of insulation	Significant reduction in annual energy with increase in embodied energy
Addition of insulation	The reduction in annual energy consumption can offset the increase in embodied energy over a period of four months (payback period).
Change in the specifications	Trade-off between Embodied energy Annual energy

D. Important Inferences from all the three studies:

- Marginal increase in Embodied energy leads to significant reduction in annual operational energy.
- This inference can be applied to improving the overall energy efficiency of buildings in hot climates of developing countries, including India, where the major portion of the building's operational energy is directed towards cooling the building and not heating.
- Additional investment of energy and therefore cost into the building envelope including better insulation of roofs and walls can be used to reduce the overall heating loads. Energy payback periods for these techniques can be calculated in a similar way.

IV. SIGNIFICANT OUTCOMES FROM OTHER SIMILAR STUDIES:

Despite the misplaced general perception that operational energy is the primary form of energy in a building, since it happens to be the bulk of the energy used during a building's lifetime, there are significant indicators of the importance of the other forms of energy. Some of these are enumerated as follows:

- Of late, there has been a spurt of the so called "zero energy" buildings that claim that all their operational energy requirements are offset by on site/ off site generation of energy. In such projects in particular, it becomes very important to assess the Embodied energy requirements, as most of the environmental impacts will be related to embodied energy.
- A study was carried out by Sartori and Hestnesin respect of three different types of buildings, namely, a conventional building, a building with low energy and a building with zero energy. Contrary to the general understanding, the results surprisingly indicate that the life cycle energy consumption in respect of zero energy building turned out to be greater than the life cycle energy in respect of the low energy building [6]. This can possibly be attributed to the higher embodied energy of materials in case of a zero-energy building, a fact that is often ignored.
- Similarly, Winther and Hestnes have established that well designed and efficiently detailed low energy buildings can be more energy efficient from the life cycle energy perspective compared to the "zero energy buildings" [6].
- Gustavsson and Joelsson have proven through studies that the construction energy in respect of low energy and conventional buildings can range from 45% to 60% of the overall energy consumption [3]. This is a significant figure that shows the importance to the construction energy in the overall scenario.
- Various national and international studies have established that the embodied energy, including the energy spent in construction is much higher than the annual consumption of energy in use. As per a research study taken up for a midrise multifamily apartment block in Allahabad, India by, Life cycle energy analysis of a house was carried out and a comparison of the embodied energy and operating energy of the building over its life span indicated that the total embodied energy requirement works out to be equal to about 9 years of the building's annual operating energy requirement[4].
- Although lesser in magnitude compared to the energy in use, the Embodied energy consumed in the production of building materials cannot be taken as insignificant in our national as well as global energy budgets for the simple reason that the building material manufacturing industry is, by and large, known to be energy intensive. It has been proven that building materials account for over 20 per cent of world fuel consumption [5].

V. Energy Consumption vs. Time Period:

While analyzing the energy usage, it is equally important to consider the time factor. Following are some important observations in respect of energy usage vs. time period of use.

- Energy consumption and GHG emissions that take place during the construction phase have known to reach high values in a very short span of time, due to the nature of construction as an activity. These are, therefore, more damaging to our environment than the emissions that occur during the operational phase.
- In general, energy consumption during the complete operational phase is higher than energy consumed in other phases. However, it is distributed over a larger life span of a building, in contrast to the energy and GHG emissions during construction, a fact that must to be considered when we are interpreting the overall energy consumption, as noted by Blengini and Carlo, Saynajoki, Karimpour [8].
- Thus, the relative importance of energy consumption and GHG emissions in the pre operational phase of building's life cycle attains higher importance Pöyry [9].
- It is imperative, therefore, to consider an overall picture with respect to energy consumption.

VI. The LCEA Approach as an Alternative for Energy Assessment:

A. Definition of LCEA:

According to International Standard ISO 14040, LCEA is a "compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [1]. Life Cycle Energy Analysis, also referred to as Life Cycle Energy Assessment, is an abbreviated form of LCEA that uses energy as the only measure of environmental impact. At a different level, the results of an LCEA can be visualised to be a broad environmental foot print of the building.

LCEA methods implemented in the building construction industry are based primarily on process-based LCEA. In a process based LCEA, the output in terms of energy consumption at each step of the entire process is calculated as per the inputs (materials and energy resources) provided.

B. Types of Process-Based LCEA Methods [1]:

- Cradle to Grave- Covers Extraction, Manufacture, Use and Disposal
- Cradle to Gate-Product life cycle- Manufacture to factory gate
- Cradle to Cradle-Includes recycling process after end of life

C. Life-Cycle Stages of a building [2]:

- Materials Manufacturing: Extraction of raw materials from Mother Earth, transporting these to the manufacturing locations, manufacturing the basic materials or components consisting of more than one material, as required,
- Construction: All activities relating to the onsite construction of the building, right from the site clearing stage to finishing.
- Use and Maintenance: Building operation stage includes the running of the building than involves the consumption of energy on account of Hvac, electricity, water supply, drainage, landscaping, waste disposal as well as repair including transport and equipment use for repair. The major components of energy consumption during the operation phase relate to Electricity and Airconditioning.
- End of Life: This stage primarily includes the energy expended in the demolition of the building and disposal of the demolition waste, including the transportation of the waste. Of late, mainly on account of the rating systems, emphasis is being laid on recycling of the materials after demolition and the same is actually being followed by some manufacturers. Therefore, activities related to recycling should also be included, which can reduce the overall energy consumption.
- LCEA for computing the Embodied energy consists of the inputs and outputs in respect of the first two stages i.e. Materials manufacturing including transportation till the site & Construction till the completion of the building i.e. ready to occupy.
- LCEA for computing the Operational Energy consists of the last two stages i.e. Use and Maintenance and End of life. Basically, it refers to the operational stage when the building is in the running mode and includes the periodic repair and maintenance. It also includes the End of life phase- primarily consisting of disposal and recycling (this is a recent phenomenon and increasingly more and more recyclable materials are being used)

D. Methodologies of performing LCEA:

The broad methodology of carrying out LCEA for the purpose of this paper can be construed to be operating at the following three levels, each consisting of sub steps as explained:

1. *Material level*: The energy assessment at the material level is at the core of the process based LCEA. In general, Architects or other building professionals do not get involved in the production of the material-level LCEA data. This is calculated by process chemists, chemical engineers, and associated specialists and submitted for inclusion in various databases.
2. *Product level:* At the product level, it is required to have a thorough knowledge of the source and quantities of the materials and manufacturing processes of the finished assembly. Since the product or the assembly is a collection of materials, the following steps need to be followed for calculating LCEA at the product level:
   - As a first step, a quantity takes off for the respective materials is calculated
   - This is followed by the consolidation of the emissions from each component.
3. *Building level:* It is the culmination of the Material and Product levels, and also sometimes referred to as Whole building LCEA. In this case, the product is the

building. The Architect is the right person for calculating the LCEA for this level, as he/ she understands the entire process. Calculation of LCEA at the building level involves the following steps:

- How the materials have arrived at site and have been assembled at site to produce components.
- How the building has been constructed
- Intended use of the building i.e.- how the building is going to be operated over time.

E. Advantages of using LCEA over the conventional means of computing the building energy:

- LCEA provides the user and the consultant with a comprehensive picture of energy utilisation through the complete life cycle of the building, covering all the stages in the building's life span.
- It includes the energy consumed during manufacturing and construction – both very important components yet often ignored. Hence the focus is not only on the energy during use but also on the choice of materials and the construction process- thus creating an awareness among the building professional as well as the end users enabling them to take a conscious call so that a building with "low" operating energy does not turn out to have a " very high" construction energy building and vice versa.
- It thus provides a greater choice to the designer and the end user in respect of the choice of materials vs. design vs. efficient running of the building, as all the three parameters have different energy implications and energy is cost.
- Currently, the greatest incentive for the Architect to use LCEA is to be able to prove to the client the long-term energy efficiency of a project using LCEA and therefore convince the client about the significant cost reduction in terms of lone term paybacks by adopting LCEA.
- Possibility of examining the trade-offs between the energy requirements of different stages, including the trade-off between embodied energy and annual energy, thereby offering greater freedom to the designer to experiment with materials, technologies and design, since the interrelationship between all these is clearly established.
- LCEA results can help in scientifically justifying the decisions taken by an Architect as well as address several questions related to energy efficiency that arise during the design and construction of a green building.

F. Impediments in adopting LCEA:

Though LCEA is undoubtedly the best tool for analysing the environmental impact of a product or project, the base data required for LCEA and the methodology for carrying it out are still in the process of being developed. It is a complex process greatly dependent on the availability, accuracy and thoroughness of the data and the reliability of the methodology being adopted. This paper has attempted to list down the following main obstacles in implementing LCEA as on date:

- *Data collection*: The task of carrying out a LCEA is constrained by the lack of readily available authentic data, thus making the job difficult for the Architect or the LCEA expert. It is unworkable for a design professional to use LCEA unless the base reference data has been scientifically collected, analyzed, tabulated and indexed in a manner that can be easily put to use [1].
- *Quality of Data:* The genuineness of Data collected from single manufacturers is questionable and therefore the data may be unreliable [1].
- *Streamlining the LCEA Process:* LCEA is a comprehensive and time-intensive process. Unfortunately, as things stand today, there is little scope for devoting time to LCEA in the overall schedule of a project covering the pre design, design, construction and post construction stages. This property of LCEA is a major hindrance in its adoption during or before building design.
- *Methodology of Impact Assessment:* LCEA is an evolving form of analysis which is based on certain observations, some assumptions as well as extrapolations from the work carried out by material scientists and building professionals. The methodology used to undertake the analysis has certain variations between one school of thought and another, though the broad framework is the same.
- *Ease of computation:* It is much easier to compute operational energy due to the established systems and processes than to compute the other forms of energy through LCEA. There is thus a greater degree of subjectivity in the computation of Embodied and Construction energies compared to operational energy which is a drawback.
- *Scarcity of the financial incentives for LCEA use:* While lucrative incentives are being provided the world over for reducing the energy footprint of buildings, most of these are in respect of the operational energy alone. In India, incentives have been announced for adoption of GRIHA in the design and construction of buildings. This is indeed a welcome move and will go a long way in bringing about significant reduction in the building energy consumption patterns in India. However, GRIHA is primarily based on ECBC, which focusses mainly on the operational energy requirements, which has been done extremely thoroughly, yet it ignores the other forms of energy. While GRIHA does have some credits for using materials with LCEA data, it does not impress upon the user or the consultant to adopt LCEA.
- *Non availability of standard benchmarks:* Another major limitation restricting the use of LCEA is the lack of standard benchmarks established by government authorities. Although BIS has come up with some codes on LCEA, these need to be specific to the materials and technologies currently being used.

VII. Role of ECBC and GRIHA towards promoting energy efficiency:

- ECBC has done a wonderful job in providing an in-depth analysis and methodology for calculation of energy requirements for different categories of buildings. However, all the energy calculations are with respect to the operational energy alone, and there is little mention of the other forms of energy.
- Besides, ECBC is mainly oriented towards urban construction and tends to ignore the large-scale rural construction in our country.
- GRIHA has taken forward the work done by ECBC and converted the document into a rating system. Undoubtedly, GRIHA has been able to bring a significant change towards bringing energy awareness among the professionals and users. While GRIHA does have credits for Embodied energy as well as Operational Energy, it does not take the holistic view that is required.

VIII. CONCLUSION AND WAY FORWARD:

In the current energy crisis facing the world, it is imperative to shift our emphasis from operational energy alone to all the forms of energy, as brought out by the above-mentioned analysis. One can conclude on the basis of the highlighted points that there is a strong justification for taking up LCEA as a tool for comprehensive energy assessment and take a holistic approach on the subject rather than a piece meal one that concentrates mainly on operational energy and ignores all other forms of energy. At the same time, as brought out by this paper, there is an immediate need to create a scientific data base in respect of embodied energy and end of life energy for different materials, streamlining and simplifying the LCEA process, which at present is non uniform across different research organizations and finally preparing a standard data base of the results of LCEA for different materials and technologies.

Moving forward, it is suggested that the following concrete measures will help bring about the much-required transformation in our approach towards energy efficiency:

- Establishment of standard benchmarks in respect of embodied energy for materials and technologies by govt. agencies like B.I. S, B.M.T.P.C and N.G. Os like C.S.E
- Replacement of the present energy assessment systems with LCEA in a phased-out manner.
- Putting in place uniform methodologies and systems, including software, for computing LCEA, based on Indian conditions. The LCEA models worked out by other countries are not fully applicable for our context and need to be modified. Also, since there are complex processes involved, along with some indeterminate areas and a vast range of materials and technologies in use in our country, besides a diverse range of climatic zones, the LCEA procedure needs to be simplified and streamlined for Indian conditions.
- Incorporation of LCEA in the major rating systems including GRIHA and LEEDS. Care needs to be taken that it is incorporated as a process driven activity and not as an outcome based -score card approach.

It is earnestly hoped that with a shift in our present approach, we shall be in a much better position to achieve the desired goals in respect of energy efficiency, both at the national and global level.

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AUTHORS PROFILE

Architect Rajesh Malik (Professor - Design Chair, School of Architecture, REVA University, Bangalore, India) has a passion for genuine sustainability which is the need of the hour. In the course of his career spanning more than three decades, he has handled a diverse range of projects, ranging from prestigious Residential developments to I.T buildings, reputed Hospitals and Hotels, at different stages of design and execution and is currently engaged in academics.

He has a flair for research as well and strongly feels there is ample scope for the same in our profession which needs to be tapped. He is particularly interested in energy efficiency and would like to contribute more towards further exploration in this field. He has till date published two papers related to energy efficiency in reputed journals besides presenting a paper on “Earth as a building Material- an objective and subjective analysis” at the 3rd Annual International Conference (Architecture and Civil Engineering. - ACE 2015), Singapore.