

機電工程署  **EMSD**
Electrical and Mechanical
Services Department

**Consultancy
Agreement No. CAO
L013 – Consultancy
Study on Life Cycle
Energy Analysis of
Building Construction**

Executive Summary of
Final Report

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Ove Arup & Partners Hong Kong Ltd

Level 5, Festival Walk, 80 Tat Chee Avenue, Kowloon Tong, Kowloon, Hong Kong
Tel +852 2528 3031 Fax +852 2268
www.arup.com

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Executive Summary

E1. Background of the Study

In response to the recommendations made by the Construction Industry Review Committee (CIRC) in 2001, the Electrical and Mechanical Services Department (EMSD) of the Government of Hong Kong Special Administrative Region initiated in 2002 a consultancy study entitled: *Life Cycle Energy Analysis of Building Construction* (hereinafter referred to as the Study).

The Study was one of the initiatives that address the recommendation of the Construction Industry Review committee (CIRC), which pinpoints on the for the following:

- a. A coherent policy framework that anchors the concept of sustainable construction firmly in the context of sustainable development; and a broad base of public support, ensuring the need for sustainability is understood in the community;
- b. Relevant model and data that support due recognition of life cycle costs and the life cycle performance of materials and components in assessing tenders; and
- c. Guidelines on use of alternative materials and systems that can help improve the environmental, energy and economic performance of buildings.

Aimed at promoting sustainable building development in Hong Kong, the major objective of the Study was to produce an assessment tool together with the required databases to facilitate local building design professionals to appraise the life cycle performance of commercial building developments in Hong Kong, in respects of their environmental and financial impacts. Quantification of the life cycle environmental and financial impacts of buildings is based on life cycle assessment (LCA) and life cycle costing (LCC) techniques.

Ove Arup & Partners Hong Kong Ltd., together with the associated sub-consultants, including The Hong Kong Polytechnic University and Levett and Bailey Chartered Quantity Surveyors Ltd., was commissioned by EMSD to undertake the Study, which commenced on 16 April 2003. This Executive Summary provides a condensed description about the major items of work undertaken in the Study and the key findings and deliverables of the Study.

E2. Literature Review

The Study began with an extensive literature review to portrait the state-of-the-art LCA development worldwide, with particular attention given to LCA methods, tools and data that had been established and can be made available. The review showed that application of LCA to building developments is still in an embryonic stage worldwide. There are a few LCA tools dedicated to assessing building designs, such as ATHENA for use in the North America, ENVEST for use in UK and EcoQuantum for use in Western Europe, but such tools, including the databases accompanying the tools, were tailor made for the locality for which they were developed. Also, it was not possible to change their databases to adapt the tools for local applications, and none of them include a detailed building energy use prediction program. It became clear, therefore, that a new tool and a new set of databases had to be developed from scratch.

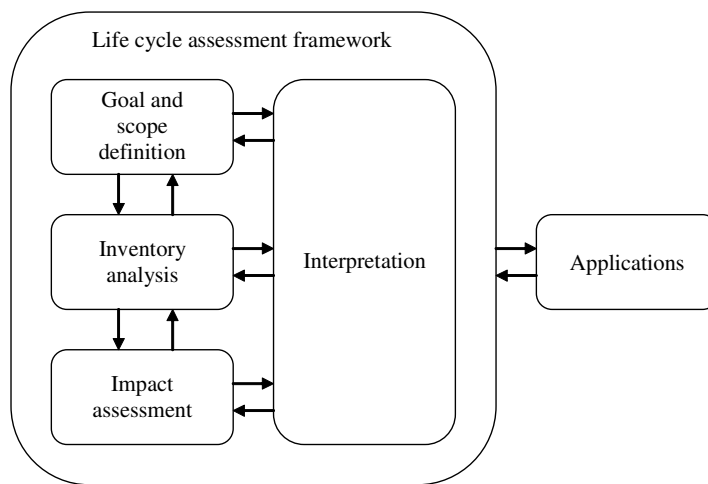


Figure 2: Phases of a LCA (adapted from ISO Standard 14040)

E3. Database for Life Cycle Analysis

The data that are essential to LCA studies are the life cycle inventory (LCI) data, which are an account of the quantities of resources consumed and emissions produced in each process involved in producing, distributing, using and finally disposing of a product. There are proprietary LCI databases available but their coverage of building and services materials and components are limited. Furthermore, the LCI data only account for consumption of such materials and components in the country of origin of the databases.

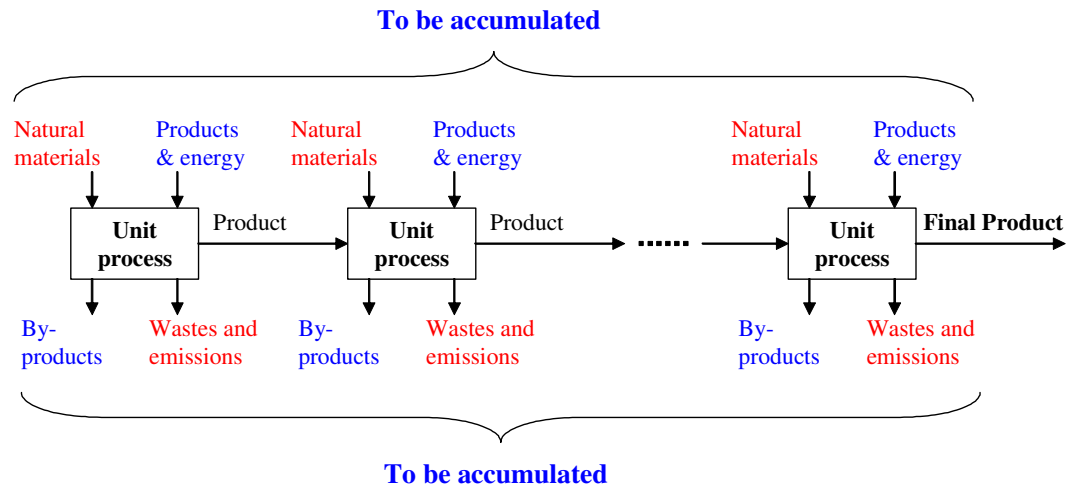


Figure 3: Flow chart of Unit Process

The approach taken to establish the data needed for LCA studies on buildings in Hong Kong was to extract the LCI data available in the proprietary databases and to edit the data to make them representative of the impacts that would be incurred due to consumption of the materials and components in Hong Kong for building construction. For this purpose, a generic LCA program was needed. Having evaluated the generic LCA programs available, one that can access the greatest number of LCI databases, embraces the widest range of standard life cycle impact assessment (LCIA) methods and can export the processed data in an appropriate format was acquired to equip the Study team with the needed tool for the development of the target LCA and LCC tool.

E4. LCA Methodology

Evaluation studies were also done to inform selection of an appropriate LCIA method for adoption. According to the 14040 series of ISO Standards, LCIA involves several steps. The major ones include:

- i) classification of the LCI data (quantities of various types of resources consumed and various types of pollutants and wastes emitted) into a number of impact categories (e.g. resources depletion, global warming, ozone depletion, acid rain, human toxicity, etc.);
- ii) characterisation of the LCI data in each impact category to yield a total impact indicator for each category;
- iii) normalisation of the characterised impact indicators by a set of reference impact indicators; and
- iv) weighting of the normalised impact indicators to yield a weighted sum, which can then be taken as a single, overall impact indicator.

Having reviewed the methods available, the CML 2 Baseline 2000 LCIA method was selected. This method embraces 10 impact categories, which are regarded as ‘must include’ in LCA studies; is based on the mid-point approach, which is scientifically sound; its details are well documented in a LCA handbook; and it can be implemented with the use of the generic LCA tool used in the Study. The 10 impact categories embraced by the CML 2 Baseline 2000 LCIA method are:

1. Abiotic depletion
2. Global warming
3. Ozone layer depletion
4. Human toxicity
5. Fresh water aquatic ecotoxicity
6. Marine aquatic ecotoxicity
7. Terrestrial ecotoxicity
8. Photochemical oxidation
9. Acidification
10. Eutrophication

The 10 impact categories embraced by the selected LCIA method have already accounted for the impacts incurred due to energy use (e.g. the associated CO₂ emissions), including embodied energy in materials, which is the energy used in producing and transporting the materials, and due to treatment of the materials when they become wastes (e.g. the associated methane emissions). However, none of the 10 impact categories are life cycle energy use or solid waste production, which are of great concern to Hong Kong. Therefore, life cycle energy use and construction and demolition waste production were included as supplementary impacts indicators in the LCA and LCC tool developed in this Study, to

provide users with these information. However, the results for these two supplementary impact categories are not used in computing the overall impact indicator, to avoid double counting.

Since numerous kinds of materials can be found in buildings, it was impossible to establish data to cover all kinds of materials that may be used in buildings. Limitations in data availability from the proprietary databases also did not permit this to be done. The Study, therefore, proceeded to survey the types and quantities of the most commonly used materials in local commercial building developments. The survey was based on data extracted from the bills of quantities (BQ) of 28 recent commercial developments in Hong Kong, which covered not only the building construction works but also the services installations in those buildings. On that basis, materials used in local building construction were prioritised according to their dominance in the life cycle impact of commercial buildings in Hong Kong. The survey work was extended to sourcing for information about local construction practices that affect the impacts of using materials in building construction, which included interviews with experienced construction practitioners, site visits and sourcing for information about wastage, and energy and water consumptions in construction sites.

For collection of required information to support the development of the databases, a survey of import statistics was conducted to find out the countries from which construction materials were imported into Hong Kong and the relative quantities imported from individual countries of origin. Data on transportation distances by shipment and by airfreight from those countries to Hong Kong and the fuel mixes used in those countries for electricity generation were also sourced.

On the basis of the information made available, and through the use of the detailed LCA program and the proprietary LCI databases purchased for use in the Study, representative life cycle impact profiles for the dominant building and building services components and materials were compiled. The life cycle impact profile of a material is the per unit quantity impacts in the 10 impact categories covered by the LCIA method. The process, referred to as the 'localisation' process, included making adjustments to the LCI data retrieved from the proprietary databases, to account for the differences in the impacts due to energy use for production of the components and materials in their respective countries of origin as well as the impacts due to transportation of the materials from those countries to Hong Kong.

For use in the normalisation step, a set of reference normalisation factors, which is the impact indicators for a reference process, had to be established. The selected reference process is the consumption of 1TJ of electricity in Hong Kong. This choice was made because the impacts incurred due to electricity consumption within the operating life of commercial buildings in Hong Kong dominate the life cycle impact of such buildings. It follows that if the LCA result for a building is X, this means that the life cycle impact incurred by the building is equivalent to the impacts incurred due to the consumption of X TJ of electricity in Hong Kong, which makes visualisation of the LCA result much easier. The cost for consuming 1TJ of electricity is also known, which is used as the normalisation factor for the life cycle cost of a building, to provide an equal basis for the LCA and LCC processes.

Furthermore, survey methods and instruments were devised for obtaining stakeholders' perceived relative importance of impacts under different categories, and between environmental and financial performances of a building development. The methods and instruments developed were used in a forum attended by stakeholders representing different segments in the local construction industry and interest groups, to unveil their subjective judgements, which provided data for determining the weighting factors for the impact categories embraced by the adopted life cycle impact assessment (LCIA) method and for weighting between life cycle environmental impact and life cycle cost.

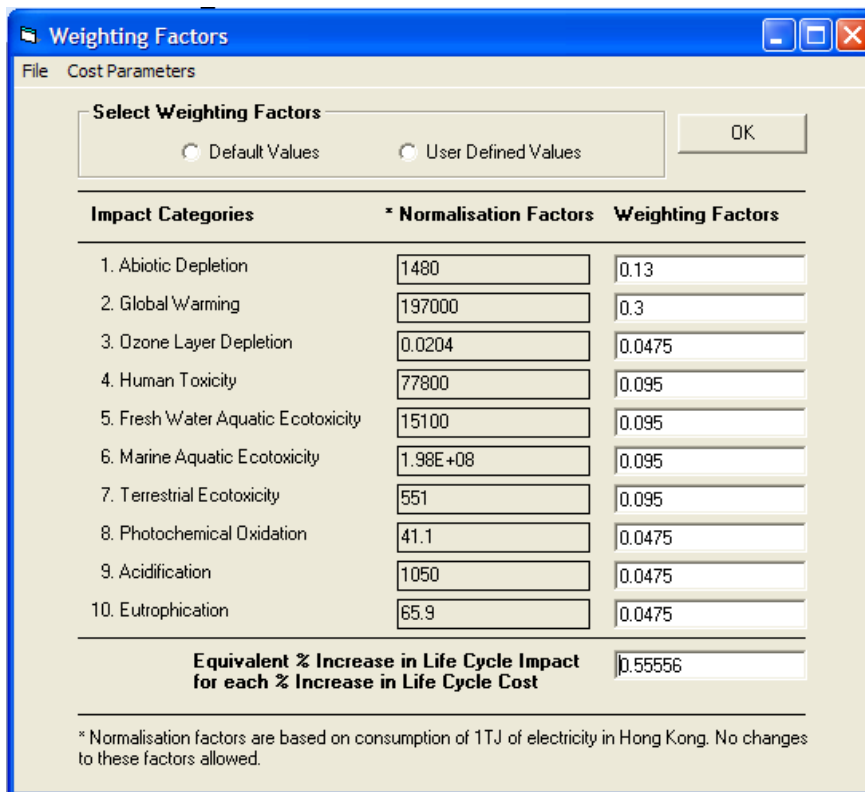
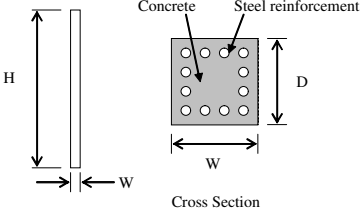
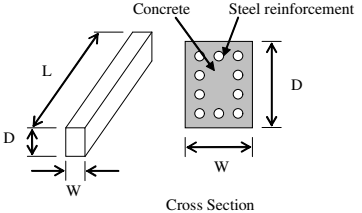


Figure 4: Normalisation and weighting factors used in the LCA and LCC program

E5. Development of LCA / LCC tool

The development of the LCA and LCC tool and the associated databases then commenced, on the basis of the methodologies developed and data compiled in the earlier stages of the Study. A life cycle impact profile (the numerical values of the 10 impact indicators per unit quantity of the material) was generated for each dominant material and the life cycle impact profiles were compiled into a database to supply the LCA and LCC tool with the essential impacts data for individual types of materials. Unit quantity costs for various materials were sourced from the Quantity Surveyor in the Study team and were incorporated into the database for life cycle cost calculations.

To ease the data input process, a range of standard elements were defined such that users of the LCA and LCC tool can conveniently assemble a model from the elements to represent an entire building and all the services systems therein. Other databases that provide essential data for the range of standard elements were also compiled. The data in these databases include: the materials that each individual element is made of; any auxiliary materials that will be consumed in the construction of the element; the range of user input data required for calculation of the quantities of different composing and auxiliary materials that will be consumed for construction of the element; and the steps of calculation to be implemented by the computing tool for determining the impacts and cost of an element.

Description	Required input data
<p>Rectangular reinforced concrete column</p> 	<p>W: Width of column cross-section (m)</p> <p>D: Depth of column cross-section (m)</p> <p>H: Height of column (m)</p> <p>m_s: Mass of steel per unit volume of component (kg/m^3)</p>
<p>Reinforced concrete beam</p> 	<p>W: Width of beam (m)</p> <p>D: Depth of beam (m)</p> <p>L: Length (span) of beam (m)</p> <p>m_s: Mass of steel per unit volume of component (kg/m^3)</p>
<p>Reinforced concrete wall and partition</p>	<p>T: Thickness of wall (m)</p> <p>W: Width of wall (m)</p> <p>H: Height of wall (m)</p>

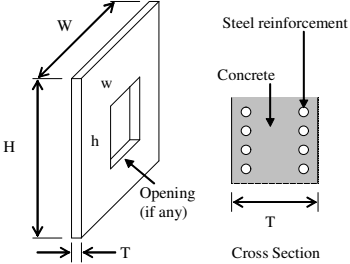
Description	Required input data
	<p>w: Width of opening (m)</p> <p>h: Height of opening (m)</p> <p>m_s: Mass of steel per unit volume of component (kg/m^3)</p>

Table 1: Examples of standard element models in the element libraries

Programming work was carried out to develop a computer program that includes: user interface modules with which a user can input data for modelling a building and to command the program to perform the calculations and to report the results; and modules for managing the user input data and the databases accompanying the program, for performing life cycle impacts and cost calculations, and for displaying and storing the calculated results. The program includes also modules for detailed building energy simulation to allow the energy use of a building during the in-use stage, which dominates the life cycle impact and cost of a building, to be included in the assessment.

The program was written in Microsoft Visual Basic, such that the program can be executed in any personal computers that run on the platform of Microsoft Windows XP, in a manner similar to common types of software for Windows XP. Besides the standard elements, the user may establish specific elements through using a generic element model. Facilities are incorporated to allow the user to make changes to the type of material, life expectance, rate of wastage and unit cost of elements to suit the user's need. Also, the user may change the default values for the weighting factors used in the LCA calculation and other parameters used in the LCC calculation. The user may also change the operating energy use predictions and the LCC calculation results, if deemed necessary.

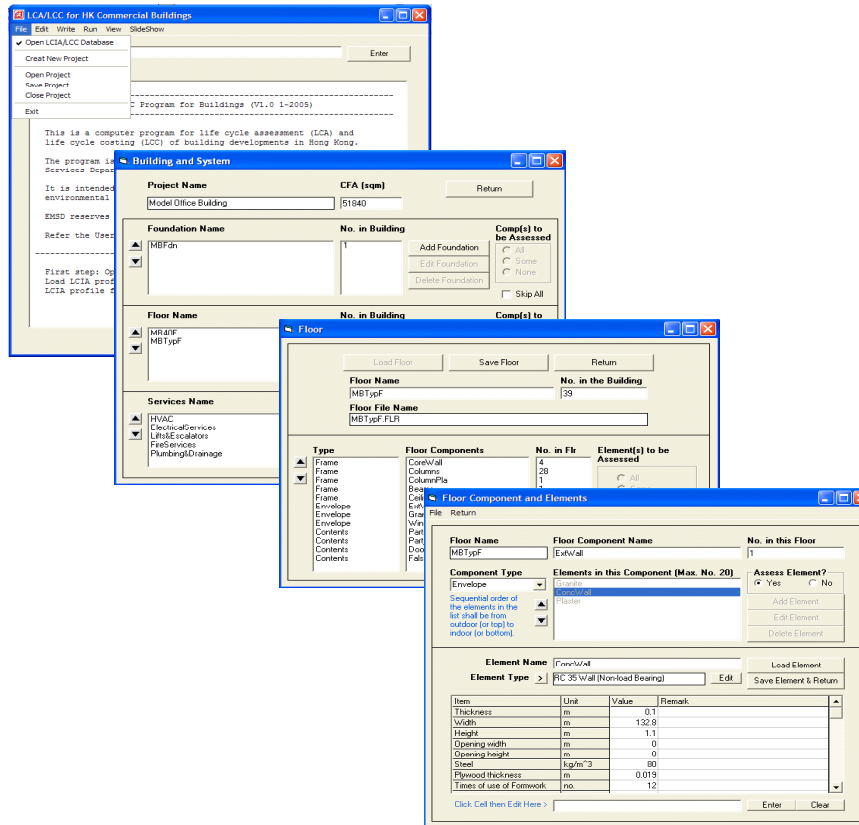


Figure 5: User interfaces for defining construction components and elements

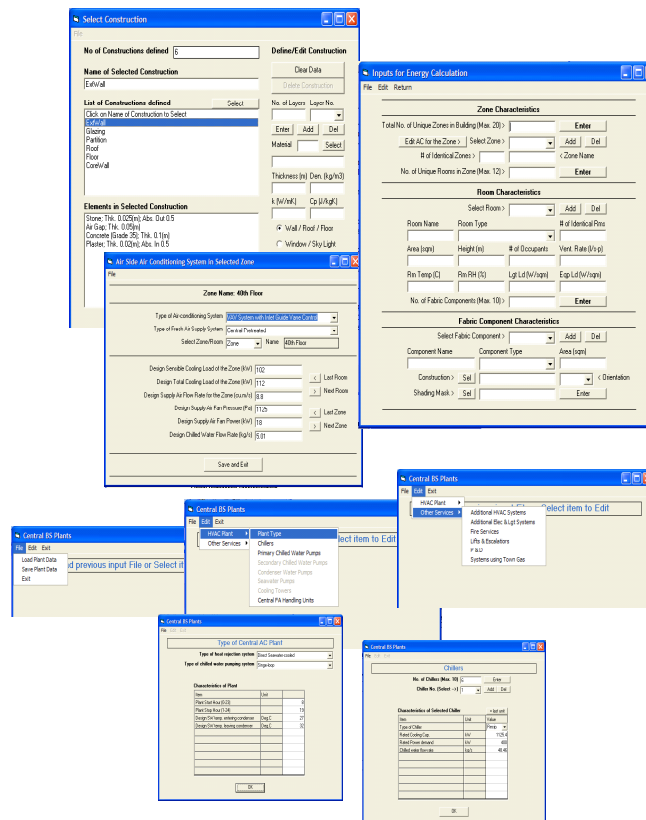


Figure 6: User interfaces for defining building and plant characteristics for energy use prediction

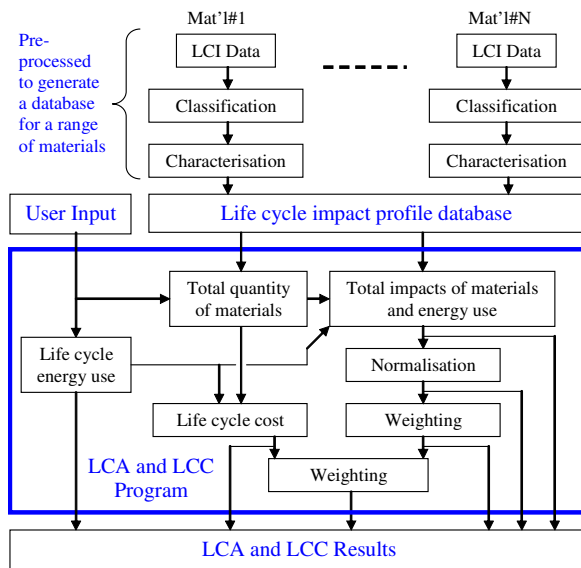


Figure 7: Relations among processes implemented within the LCA and LCC program

The screenshot shows the 'LCA/LCC Results' window. It includes dropdown menus for 'Case' (Current Case), 'Building Parts' (Whole Bldg.), and 'Life Cycle Stage' (Whole Life Cycle). A 'Show Data' button is present. The main table displays the following data:

Impact Categories	Characterised	Unit	Normalised	Weighted
1. Abiotic Depletion	3589835	kg Sb eq.	2425.564	315.3233
2. Global Warming	4.845342E+08	kg CO2 eq.	2459.564	737.8694
3. Ozone Layer Depletion	55.99266	kg CFC-11 eq.	2744.738	130.3751
4. Human Toxicity	3.389223E+08	kg 1,4-DB eq.	4356.328	413.8511
5. Fresh Water Aquatic Ecotoxicity	3.565293E+07	kg 1,4-DB eq.	2361.121	224.3065
6. Marine Aquatic Ecotoxicity	4.806584E+11	kg 1,4-DB eq.	2427.568	230.6189
7. Terrestrial Ecotoxicity	1306970	kg 1,4-DB eq.	2371.997	225.3397
8. Photochemical Oxidation	104236.5	kg C2H2	2536.168	120.468
9. Acidification	2603175	kg SO2 eq.	2479.214	117.7627
10. Eutrophication	177933	kg PO4 eq.	2700.045	128.2521
11. Energy Use	2.657944E+09	MJ	Tot. Imp. (Cat.1-10) > 2644.167	
12. Solid Waste	4.662198E+07	kg	Stage / LC Cost (HK\$) > 8.307923E+08	
Total LCA/LCC Score >				4450.25

At the bottom, it states 'Data computed for the CURRENT Case.' and includes a 'Show Charts' button.

Figure 8: Main output form in the LCA and LCC program

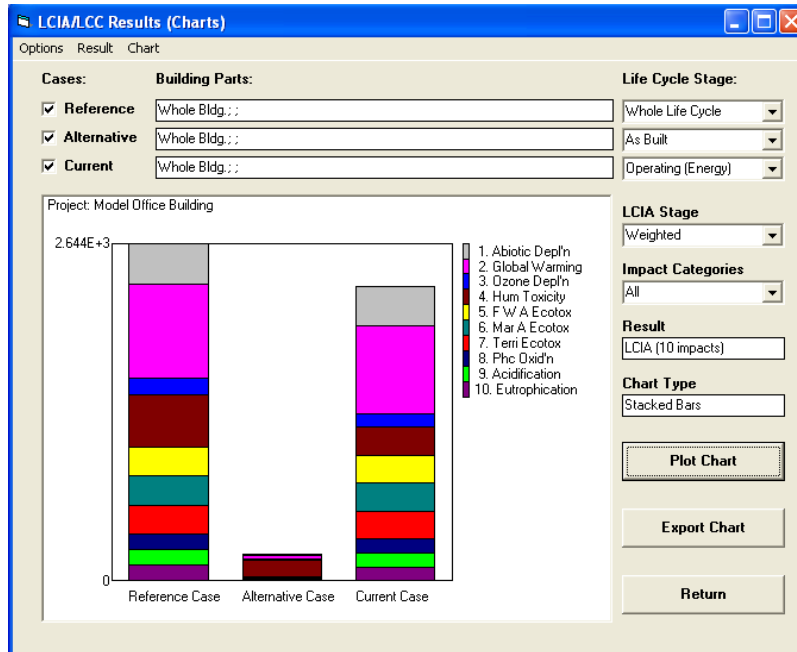


Figure 9: Graphical output form in the LCA and LCC program

E6. Other Deliverables

The other deliverables of the Study include a detailed user manual and a document that presents an application example of the program, which are for providing guidance to users on how to make use of the program to conduct LCA and LCC of buildings. A series of seminars and workshops had also been conducted to introduce the tool to practitioners in the local construction industry.