

DEVELOPING LIFE CYCLE ASSESSMENT TOOL FOR BUILDINGS IN HONG KONG

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ABSTRACT

Life Cycle Assessment (LCA) in many ways is a methodology which building industry is looking towards to give the answers on how to assess sustainability of buildings. In Hong Kong, like many other countries, its application is limited by the availability of credible assessment tools in the market. This paper provides the details on the processes and findings of a comprehensive study initiated by the Government to derive a LCA tool for the use of the local building industry, addressing on researches that are needed to really make LCA part of the answer to sustainability assessment.

KEYWORDS

Life Cycle Assessment, LCA, sustainability, building materials

INTRODUCTION

Global Perspective of Sustainability and Life Cycle Assessment

Global recognition of the need to strive for sustainable development began with the 1987 Report of the World Commission on Environment and Development: "*Our Common Future*", and subsequently manifested by the 1988 United Nations Environment Programme (UNEP), the 1992 Earth Summit at Rio de Janeiro, the 1997 Kyoto Protocol and the 2002 Earth Summit at Johannesburg. The Rio Earth Summit has led to the emergence of Agenda 21, the action plan for achieving sustainable development. The Malmö Declaration emphasised the importance of the life cycle economy as the overall objective for the development of cleaner and more resource efficient technologies. LCA is identified as a quantitative tool to support decision making for a sustainable development.

What is Life Cycle Assessment (LCA)?

LCA can be used both as a tool for assessments and a concept in discussions and evaluations. As a tool, LCA makes it possible to study which raw materials and energy types are used in producing products or providing services; to identify which discharges arise from a specific source to air, water and soil; and to assess the environmental impact of the identified discharges. As a concept, it represents a way of thinking about and looking at products and materials from cradle to grave, to categorise problems and assign priorities in finding a solution, and to foster consensus and international co-operation.

The multi-criteria study done in 1969 for Coca-Cola on the choice between glass and plastic bottling is believed to be the first LCA study ever conducted (Ecobilan, 2003). As a topic in environmental management, the history of LCA dates back to the early 70's (Guinee, 2002). However, active development and application of LCA has only a relatively short history. It is not until recently that a standardized LCA framework was established by ISO Standard 14040. The procedures involved are summarized in the following diagram.

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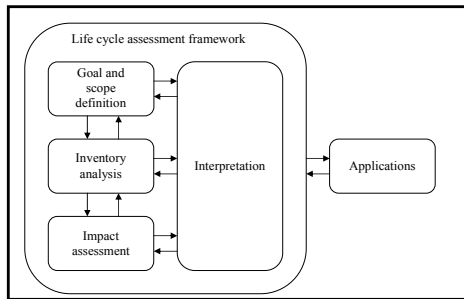


Figure 1. Framework of LCA study.

Scope of LCA

A product system comprises a collection of unit processes, each of which performs one or more defined functions, connected by flows of intermediate products, as depicted in Figure 2. The system boundary defines the unit processes to be included in the system to be modelled, which is to be determined taking into account the intended application, assumptions made, cut-off criteria, data and cost constraints, and the intended audience. As an LCA is meant to be a cradle-to-grave analysis, the original sources of raw materials; distribution and transportation processes; use and maintenance of products; process wastes; and product reuse, recycling, energy recovery and product disposal are processes and flows that should be included in the LCA.

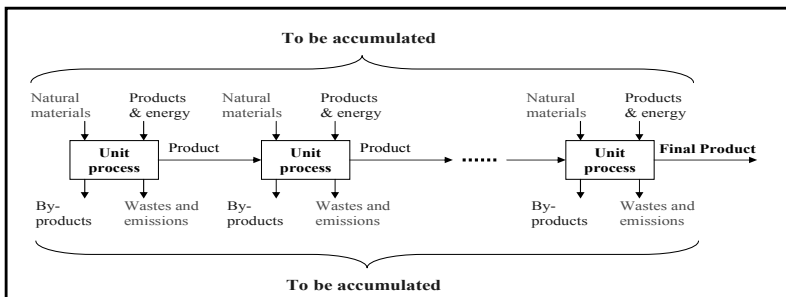


Figure 2. Scope of LCA analysis

The type of inputs and outputs that an LCA should embrace, and data for which should be collected, include:

- Energy inputs, raw material inputs, ancillary inputs, other physical inputs;
- Products; and
- Emissions to air, water and land, and other environmental aspects.

The inputs and outputs of a process may also be classified into economic flows and environmental interventions, as depicted in Figure 3.

The criteria used in LCA practice to decide which inputs and outputs are to be studied include:

- Mass - All inputs/outputs that cumulatively contribute more than a defined percentage to the mass input/output of the product system
- Energy - Those inputs/outputs that cumulatively contribute more than a defined percentage of the product system's energy input/output

- **Environmental relevance** - Inputs/ outputs that contribute more than an additional percentage to the estimation quantity of each individual data category (e.g. sulphur oxides) of the product system.

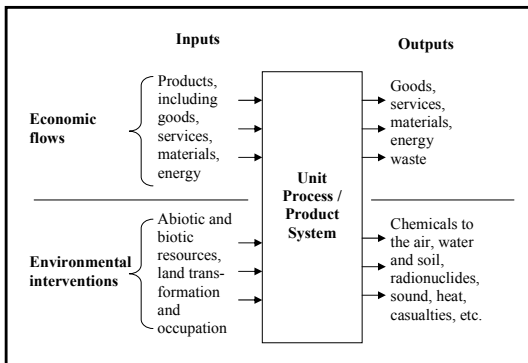


Figure 3. LCA process

Importance of Local Database

Due to the vast amount of data and processes involved, LCA practitioners need to be equipped with an appropriate calculation and data management tool for conducting LCA studies. The LCA tool should have access to databases that provide data for relevant systems and processes such that a model can be conveniently assembled for the product system under concern, and the inventory data made available for the impact assessment and interpretation of results. Expert knowledge is required for gathering inventory data and quantification of impacts. It embraces a diverse range of subject areas, such as environmental science, ecology, organic and inorganic chemistry, medical sciences, construction, economics, mathematics, mechanical, electrical, manufacturing and chemical engineering, etc. Even an LCA practitioner would need to be equipped with relevant and accurate inventory and cost data for all the materials and products involved, and an adequate LCA calculation tool, for conducting an LCA study. The current study, initiated by EMSD of HKSAR, was conducted with this background.

METHODOLOGY OF LCA TOOL FOR HONG KONG

To illustrate the essential features required of the LCA model to be developed in this study, a building is regarded as a product and the product life cycle is divided into the following phases (USEPA, 2003):

- Cradle to entry gate
- Entry gate to exit gate
- Exit gate to grave

The cradle to entry gate phase starts from extraction of raw materials and embraces all the processes for producing the construction materials and components required and bringing them to the site for constructing the building. The inventory data required include all the economic flows which embrace, in addition to the raw materials, any recycled and reused materials, intermediate products, and the energy and ancillary inputs required for the production and transportation of the construction materials and components. All the impacts (emissions or releases) incurred in these processes, which are the environmental interventions, are another essential part of the inventory data.

The entry gate to exit gate phase corresponds to the construction phase of a building. During this phase, materials and energy are consumed and construction wastes generated, which add to the inventory. However, data relevant to the local construction industry are at present lacking. Survey

studies would, therefore, need to be conducted to collect data specific to local construction activities (see later descriptions on survey methods devised for data collection). To facilitate comparison studies on alternative designs or material uses, the material and energy use during the construction phase would need to be broken down into those incurred by individual types of materials and components.

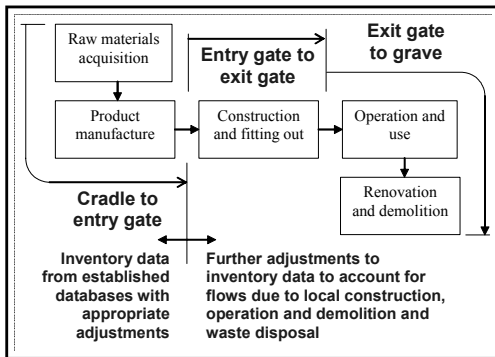


Figure 4. Stages of Building Life Cycle.

To address the need for an efficient tool for predicting the recurrent energy use in commercial buildings in Hong Kong for use in LCA assessments, a novel building energy prediction model will be developed for predicting the annual energy use for air-conditioning in buildings. An alternative model will retain the theoretical rigour required for accurate prediction of building cooling load and plant energy use, but seeks to substantially enhance the computational efficiency such that prediction of the annual energy use can be accomplished within much shorter time than what would be required if a conventional detailed building energy simulation program was used. **Figure 5** compares the calculation methods used in a conventional detailed simulation program and in the alternative method.

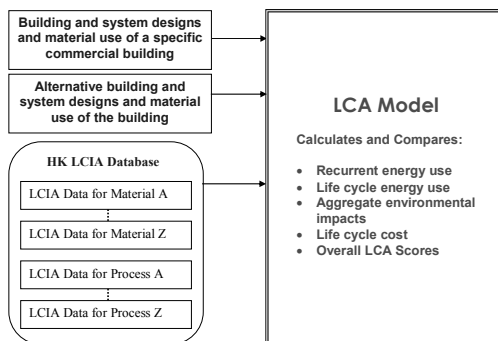


Figure 5. Model of LCA for Buildings in Hong Kong

The results of these studies will allow a database that contains the LCI data (the economic and environmental flows) for the major building materials and components, and building services equipment and materials to be established. Calculation routines will be developed for performing the classification, characterisation, normalisation and weighting processes.

PROCESSES OF DEVELOPING LCA TOOLS

Survey of Building Materials and Services in Hong Kong

A LCA model relies on a life cycle inventory (LCI) database to provide data about the economic flows and environmental interventions that would be incurred by consumption of materials and energy for construction, operation and demolition of buildings. A sample of representative commercial buildings has been selected as a basis for identification of the most commonly used building and building services components and materials among commercial buildings in Hong Kong. To ensure the obtained data would be representative of the current local building construction practices and reasonably comprehensive, the sample buildings are selected from a random list of commercial buildings on the basis of the following criteria:

- The selected buildings must be either completed within the past ten years or are under construction at the moment for completion. This is to forecast a meaningful indication of potential impacts for future buildings from latest development;
- Information and details for any selected building should be complete, readily available and accessible;
- The sample must represent a wide range of built forms, scale, grades, designs and specifications;
- The sample must embrace buildings equipped with different types of building services systems.

Four Government office buildings have also been included in the survey for comparison of different purpose-built office buildings. In total, the building samples include 28 buildings, among which there are 16 private office buildings, 4 government office buildings, 4 retail centres and 4 hotels.

In this inventory study, four private commercial buildings of medium to small scale were selected in order to obtain an indicative picture about the potential outcomes and refine the methodology. In general, the major sources of information are the priced bills of quantities for the successful bids, technical specifications, tender documents and relevant materials submitted by the contractors in their tenders. Given that LCI data relevant to Hong Kong are basically unavailable, supplementary questionnaire surveys and interviews will have to be conducted with material suppliers, design consultants, contractors and building management companies to find out the countries of origin of the materials, components and equipments; the means used for their transportation to Hong Kong; and the common local practices of using material, equipment and systems in buildings, including for the maintenance and refurbishment work during the occupied stage.

Survey of Building Services in Hong Kong

This part of the Study aims to enable the impacts of services systems in commercial buildings to be estimated at the design stage to facilitate comparisons of alternative designs. The life cycle impacts to be evaluated should include the impacts of using resources for the production, transportation and installation of services systems and equipment, the total operating energy use of services systems and equipment during the occupied stage of a building, and the impacts of demolition and disposal of equipment and materials.

At the stage of building design where alternative services system designs are being considered, details of the system designs would not have been made available. For an instance, when a designer is considering using either fan coil systems or VAV systems for the office floors in a commercial building, the exact quantities, dimensions and capacities of air ducts, fan coil units or air-handling units and VAV boxes would not have been determined. Therefore, figures based on best engineering design would need to be established as default values for use in an LCA study to facilitate design decision-making. Nonetheless, the LCA software should allow the user to change the default values to better reflect the system designs under concern.

Similar to building components and materials for constructing buildings, a statistical analysis of design information pertaining to existing building development projects should be conducted to find out the types, quantities and key characteristics of services systems and equipment that are in common use in commercial buildings in Hong Kong. The study should proceed with identification of commonly used

types of services systems and equipment in commercial buildings in Hong Kong, based on all buildings in the sample, to unveil the relation between building/premises types and choices of system designs. The study should identify also special system/equipment being used for enhancing environmental performance or energy efficiency of basic services systems, e.g. PV panels, air-to-air heat recovery wheels, light pipes etc. A list of common services systems that can often be found in commercial buildings in Hong Kong is shown in Table 1.

Adjustment for local and on-site construction processes

For ascertaining the energy uses and the local environmental impacts that are incurred during the construction stage, the survey will include interviews with and data collection from main contractors and sub-contractors of building projects, and companies providing local transportation services for materials and components. The survey will also cover companies responsible for off-site work, e.g. production of ready-mix concrete and pre-fabricated components. Although it would be difficult to obtain comprehensive and accurate data from such surveys, it should be possible to obtain estimates for various major construction processes that take place at different phases of the construction project by conducting necessary work studies to collect critical information, e.g. number of truck-loads, travel distances and data on fuel use per km for trucks, and the types and patterns of use of major construction equipment, for estimating the environmental impacts associated with different onsite construction processes.

Table 1. List of common building services systems and equipment

Basic installations:	
Heating, ventilating and air-conditioning (HVAC) installations	
Lighting installations	
Power distribution systems (Electrical installations), including essential power supply systems	
Vertical transportation (lift and escalator) installations	
Plumbing and drainage systems	
Fire detection and protection systems	
Automatic refuse collection systems	
Grey water recycling systems	
HVAC systems:	
Air-side systems:	<ul style="list-style-type: none"> All air systems, including: <ul style="list-style-type: none"> - Constant air volume systems - Variable air volume systems with and without variable speed drives - Dual conduit systems (CAV/VAV systems) - Dual duct systems (with mixing VAV terminals) Air-water systems, basically primary air fan coil systems
Water-side systems:	<ul style="list-style-type: none"> Heat rejection methods, including: <ul style="list-style-type: none"> - Direct air-cooled systems - Indirect air-cooled systems (water cooled chillers with radiators) - Direct seawater-cooled systems - Indirect seawater-cooled systems (with seawater/fresh water heat exchangers) - Evaporative cooling (water cooled chillers with cooling towers) Chilled water pumping systems, including: <ul style="list-style-type: none"> - Single-loop pumping systems - Two-loop pumping systems with and without variable speed secondary pumps Space/water heating systems, including: <ul style="list-style-type: none"> - Electric duct heaters - Electric water heaters - Reclaimed condenser heat (for space heating or water pre-heating) - Air and water-source heat pumps (for space heating or water pre-heating)
Lighting installations:	
Various types of lamps, including T8 and T5 fluorescent lamps with and without electronic ballast, compact fluorescent lamps, GLS lamps, tungsten halogen lamps, LED lighting, etc.	
Additional devices:	<ul style="list-style-type: none"> Dimming control using light sensors and/or occupancy sensors On/off timer control (discrete or through building management system) Zonal wiring Light pipes
Electrical installations:	

Major equipment, including transformers, switch boards, cables, bus-bars, wiring, conduits, sockets etc.
 Standby generators
 Power factor improvement devices
 Power quality control devices
 Renewable sources, e.g. photovoltaic cells

LOCAL DATA OF BUILDING MATERIALS AND SERVICES SYSTEMS

Building Material Usage

According to the survey findings, concrete, rebar, plaster, render & screed together would contribute more than 83% of the total weight of building materials used in these buildings. Concrete alone would already contribute more than 70% of the total weight of building material in a building; rebar would contribute 6-7%, and plaster and render 5-6% of the total weight of a building. Other materials, including structural steel and bricks and blocks together, would only contribute up to 17% of the total building weight in all types of buildings (Table 2).

Table 2. Summary of Quantity Factors by Material Group for the Selected Buildings

	Range	
	From	To
Construction Floor Area (CFA)		
Total Weight of Building Materials Used per m ² CFA	1,903 kg/m ²	3,313 kg/m ²
Material Group		
Acoustic Insulation	0.04 kg/m ²	6.61 kg/m ²
Aluminium	5.65 kg/m ²	12.85 kg/m ²
Asphalt and Bitumen	0.00 kg/m ²	3.22 kg/m ²
Bricks and Blocks	9.74 kg/m ²	37.60 kg/m ²
Concrete	1,358.38 kg/m ²	2,650.90 kg/m ²
Formwork	3.13 m ² /m ²	4.21 m ² /m ²
Galvanised Steel	3.37 kg/m ²	23.59 kg/m ²
Glass	10.82 kg/m ²	14.67 kg/m ²
Paint	1.08 kg/m ²	2.59 m ² /m ²
Plaster, Render and Screed	93.45 kg/m ²	151.34 kg/m ²
Plastic Laminate	0.05 kg/m ²	0.42 kg/m ²
Plywood	0.16 kg/m ²	0.79 kg/m ²
Reinforcing Bar	101.76 kg/m ²	255.95 kg/m ²
Stainless Steel	1.19 kg/m ²	15.99 kg/m ²
Stones	0.33 kg/m ²	36.77 kg/m ²
Structural Steel	49.04 kg/m ²	102.77 kg/m ²
Thermal Insulation	0.12 kg/m ²	1.16 kg/m ²
Tiles	3.12 kg/m ²	38.36 kg/m ²
Vinyl Tiles / Vinyl Sheet	0.00 kg/m ²	0.03 kg/m ²
Acoustic Tiles	0.00 kg/m ²	0.11 kg/m ²
Calcium Silicate Board / Fibre Reinforced Calcium Silicate Board	0.00 kg/m ²	0.26 kg/m ²
Firestop Insulation	0.00 kg/m ²	0.38 kg/m ²
Plasterboard	0.00 kg/m ²	2.18 kg/m ²
Plastic, Rubber, Polymer	0.09 kg/m ²	4.17 kg/m ²
Solid Surfacing Material	0.00 kg/m ²	0.04 kg/m ²
Cement Board	0.00 kg/m ²	1.08 kg/m ²
Durasteel	0.00 kg/m ²	0.25 kg/m ²
Special Aggregates (Dynagrip; in non-skid finish)	0.00 kg/m ²	0.15 kg/m ²
Access Floor Panel (Chipboard Core & Galvanised Steel)	0.00 kg/m ²	13.39 kg/m ²
Fireproofing Coating / Paint on Structural Steel	0.00 kg/m ²	0.00 kg/m ²
Photovoltaic System	0.00 m ² /m ²	0.01 m ² /m ²

The impacts in respect of the embodied energy, CO₂, SO₂ and dust emissions per square meter of CFA contributed by the building materials of the studied buildings were also determined. The embodied energy content per square meter of CFA for a building ranges from 9,448-10,907 MJ/m²; the corresponding ranges of CO₂, SO₂ and dust emissions are respectively 639.96-783.22 kg/m², 0.89-1.22 kg/m², and 43.8-45.27 kg/m². The differences in the overall values of the four types of impacts among the four buildings are relatively small, generally less than 13% from their means.

Building Material Usage

Figure 6 shows the embodied energy content, CO₂, SO₂ and dust emission impacts of various building services systems installed in the four buildings. The HVAC systems contribute the greatest impacts, followed by electrical services and fire services systems.

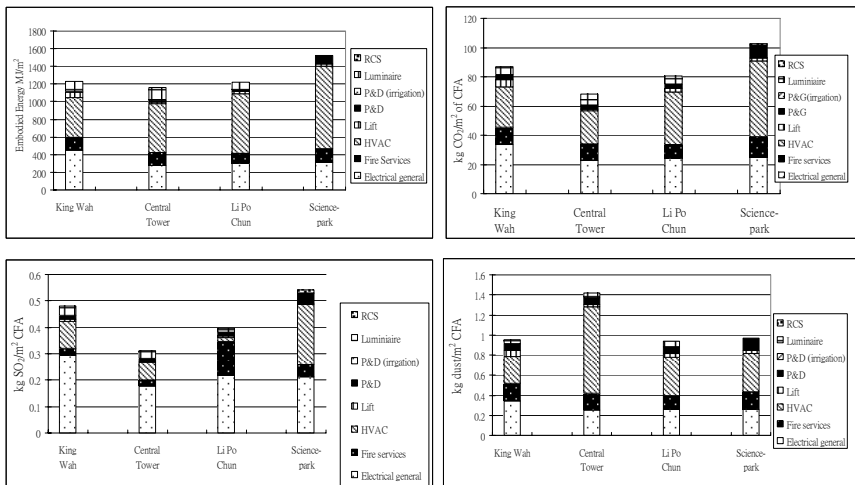


Figure 6. Impacts of various building services systems installed in buildings

From the survey of the different components within the Electrical Services, Fire Services, HVAC, and Plumbing and Drainage Systems, the main and sub-main cables in conjunction with lighting and power system contributed to majority of the impacts (76% of overall CO₂ emission impact; 83% of overall SO₂ emission; 79% of overall dust emission); pipes of the Fire Services Systems contributed to the majority of the impacts (97% for CO₂; 80% for SO₂; 97% for dust); water side piping together with air side ductwork also contributed to the majority of the impacts (66% for CO₂; 59% for SO₂; 90% for dust); while pipes also contribute 85% of overall CO₂ emission impact; 83% of overall SO₂ emission; 61% of overall dust emission.

CONCLUSIONS

Developing a LCA model for the use of the building industry is a complicated process. Reliable database on the usage of material and services in buildings as well as the LCI inventory of the materials used are the pre-requisite of succeed. Extensive localization processes as discussed in this paper are necessary. The final LCA model developed can be used as a design tool for optimizing building design or a decision tool that assesses the sustainability of the buildings.

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