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# Comparative Embodied Carbon Analysis of the Prefabrication Elements compared with In-situ Elements in Residential Building Development of Hong Kong

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***Abstract*—**This paper reviews the greenhouse gas emissions of prefabrication elements for residential development in Hong Kong. Prefabrication becomes a common practice in residential development in Hong Kong and is considered as a green approach. In Hong Kong, prefabrication took place at factories in Pearl River Delta. Although prefabrication reduces construction wastage, it might generate more greenhouse gas emission from transportation and manufacturing processes. This study attempts to measure the "cradle to site" greenhouse gas emission from prefabrication elements for a public housing development in Kai Tak area. The findings could help further reduction of greenhouse gas emissions through process improvement.

***Keywords*—**Prefabrication, greenhouse gas emission, cradle-to-site, residential development

## I. Introduction

PREFABRICATION becomes a common practice in residential development in Hong Kong. Hong Kong will run out of landfill area for municipal solid waste within ten years [3]. To reduce the construction wastage of the municipal solid waste in Hong Kong, prefabrication is one of the ways to reduce waste on site. In recent years, public housing development adopts products, such as precast façade, precast wall, precast stair, precast tie beam and precast landing, to reduce construction waste. The application of prefabrication attempts to reduce construction wastage, enhance quality, workmanship and safety during construction.

Most of the local studies concern the reduction of construction wastage from prefabrication during construction stage. However, it seems there is no study concerning the greenhouse gas emission from prefabrication from "cradle to site" stage that includes raw-material extraction, prefabrication manufacturing, and transportation from extraction location to factory and from factory to site.

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Although prefabrication reduces construction wastage, it might generate more greenhouse gas emission. In Hong Kong, prefabrication took place at factories in Pearl River Delta. Some of the raw-materials might source from Hong Kong. The travel distance will be double-up as raw-materials will travel from Hong Kong to Pearl River Delta and to Pearl River Delta and back to the construction site in Hong Kong. The real benefit from prefabrication on the reduction of "cradle to site" greenhouse gas emission in Hong Kong's context is unclear.

This study attempts to measure the "cradle to site" greenhouse gas emission from prefabrication elements (precast facade, precast wall, precast stair, precast tie beam, precast landing, precast refuse chute, semi-precast slab) for a public housing development in Kai Tak area. The prefabrication factory was located at Shenzhen, China. The greenhouse gas emission from the raw-material extraction, prefabrication manufacturing, and transportation from extraction to factory and from factory to site was accounted. Improvement scheme would be proposed in this paper to reduce the greenhouse gas emission of prefabrication elements.

## II. Methodology

The accounting of the greenhouse gas emission commences on March 2011. We follow the Life Cycle Assessment methodology for the accounting and reporting of the greenhouse gas emission for the "cradle to site" stages, including:

- Raw-material extraction,
- Transportation of raw-materials to prefabrication factory,
- Prefabrication manufacturing, and
- Transportation of prefabrication factory to construction site

Prefabrication elements used in the Kai Tak construction site comprises of precast facade, precast wall, precast stair, precast tie beam, precast landing, precast refuse chute, semi-precast slab. The precast elements were basically reinforced concrete components prefabricated in factory with rebar exposed at the end. Precast façade would install with aluminium window frame. Glasses will be installed on site later after delivery.

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Fig. 1 Precast facades

Fig. 2 Precast staircases

Fig. 3 Precast refuse chute

Fig. 4 Semi-precast slab

The Life Cycle Assessment (LCA) was carried out for the manufacturing and transportation phase of 2,500 numbers of prefabrication elements during the production period of April 2011. The LCA took account of all the background information, like raw material extraction, manufacturing and transports (cradle to site). For data source, checklists were sent to the following the prefabrication factory responsible for the production of prefabrication elements for the public-housing development of Kai Tak area. Data request comprised of quantities and types of raw-materials, fuel, waste and equipments used in the production of 2,500 numbers of prefabrication elements for production period. As per the information of factory, one set of steel formwork will use 36 times. Fig. 4 shows the quantities of the raw-materials and the quantity of the steel formwork used in the production of the 2,500 numbers of prefabrication elements in the public housing development in Kai Tak Area. Fig. 5, Fig. 6 and Fig. 7 shows the quantity of fuel, solid wastage and recycled waste of the 2,500 numbers of prefabrication elements in the public housing development in Kai Tak area. Fig. 8 shows the truck transport distance from raw-material extraction to prefabrication factory and from prefabrication factory to the construction site in Kai Tak area.

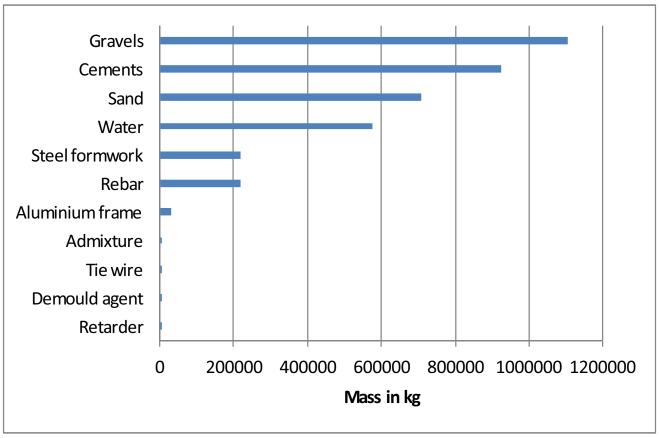


Fig. 4 The quantities of raw-materials or primary products of 2,500 numbers of prefabrication elements for a public housing development in Kai Tak area

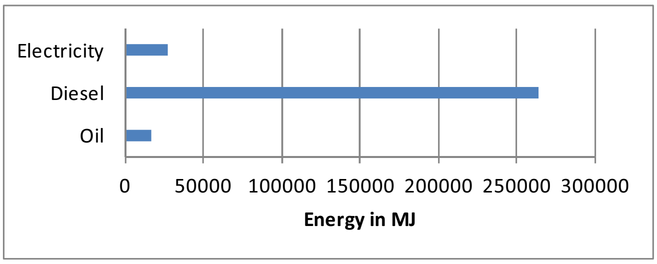


Fig. 5 The quantities of fuel used in the construction of 2,500 numbers of prefabrication elements for a public housing development in Kai Tak area

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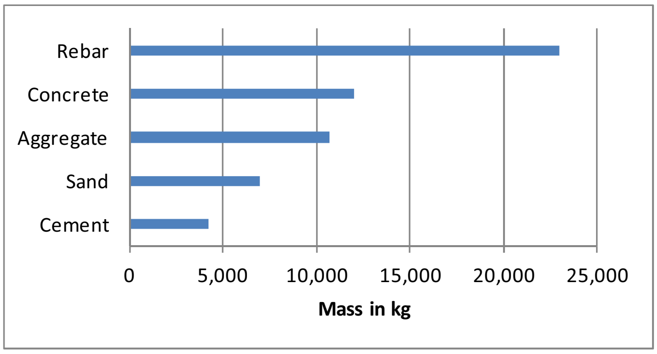


Fig. 6 The quantities of solid wastage from the production of 2,500 numbers of prefabrication elements for a public housing development in Kai Tak area

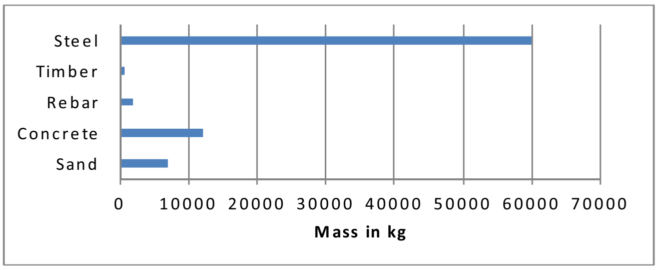


Fig. 7 The quantities of recycled wastage of 2,500 numbers of prefabrication elements for a public housing development in Kai Tak area

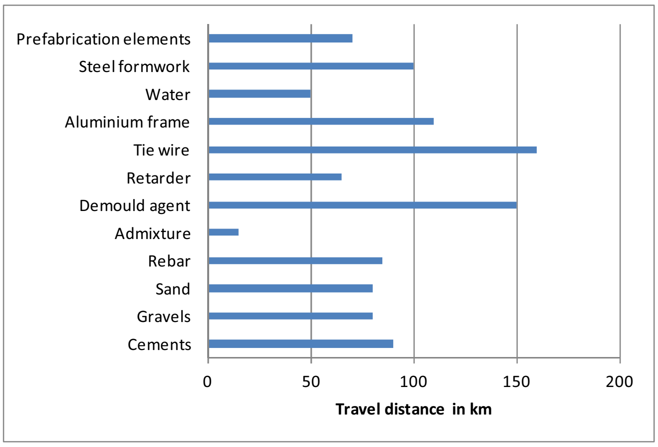


Fig. 8 The travel distance from raw-material extraction site to prefabrication factory for production of the 2,500 numbers of prefabrication elements for a public housing development in Kai Tak area

## III. Hypothesis Basecase

To find out the benefit or drawback on carbon emission, a hypothesis base case was set up. The following table shows the cases, production period and "cradle to site" stages for comparison. Raw-materials including rebar and retarder, were sourced from Hong Kong. Fig. 9 shows the truck travel distance for the raw materials for in-situ construction of 2,500 numbers of elements. Transport carbon coefficient ("gate to site") "cradle to gate" embodied carbon coefficient was referred to the figure from Department for Environment, Food and Rural Affairs (DEFRA) published by UK Government in 2008 and UK figures. The references of electricity carbon coefficient of China Light Power (CLP) electricity and electricity in Shenzhen is extracted from [2]-[10], respectively.

TABLE I
The Design Case and Hypothesis Basecase

| Prefabrication elements – 2,500 numbers<br>Production Period (April 2011) | In-situ elements - 2,500 numbers<br>Hypothesis Base (Production Period April 2011) |
|---|---|
| "cradle to site" stages<br>1. Raw-material extraction<br>2. Transportation from extraction site to prefabrication factory at Shenzhen<br>3. Manufacturing of prefabrication elements at prefabrication factory at Shenzhen<br>4. Transportation from prefabrication factory to construction site at Kai Tak area | "cradle to site" stages<br>1. Raw-material extraction<br>2. Transportation from extraction to construction site at Kai Tak area, Hong Kong<br>3. In-situ construction at Kai Tak area, Hong Kong |

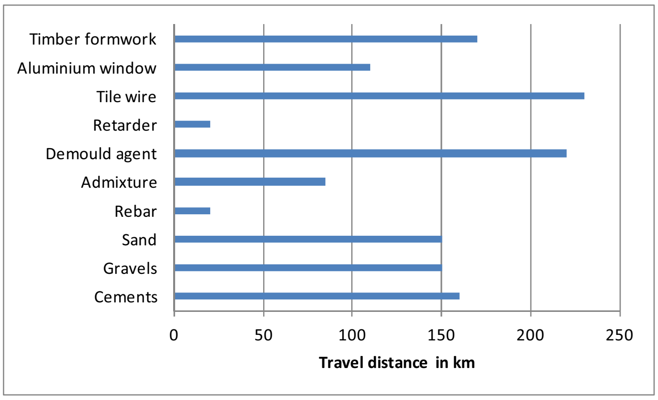


Fig. 9 The travel distance from raw-material extraction site to construction site for production of the 2,500 numbers of prefabrication elements for a public housing development in Kai Tak area

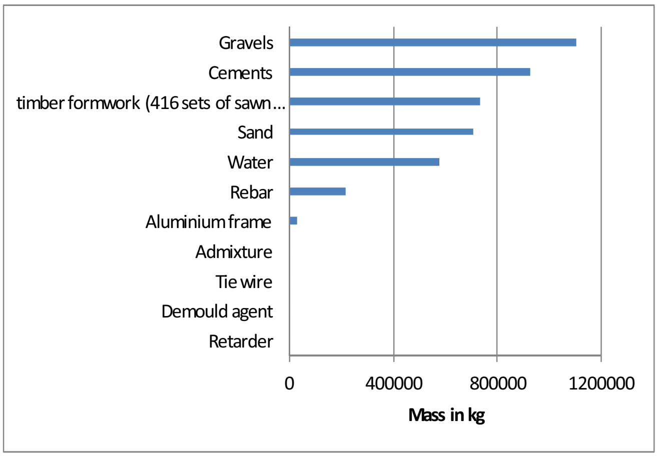


Fig. 10 The quantities of raw-materials or primary products of 2,500 numbers of in-situ elements for hypothesis basecase

## IV. Results

Fig. 11 shows the total carbon emissions for prefabrication elements and hypothesis in-situ elements (basecase) for raw-material extraction, prefabrication manufacturing and transportation stages. The 2,500 numbers of prefabrication units emit a total of 2,212 tonne carbon emission. Compared with the hypothesis basecase (in-situ elements), the carbon emission is 134 tonnes less than in-situ elements. It is equivalent to the carbon absorption of 5,826 numbers of trees per year.

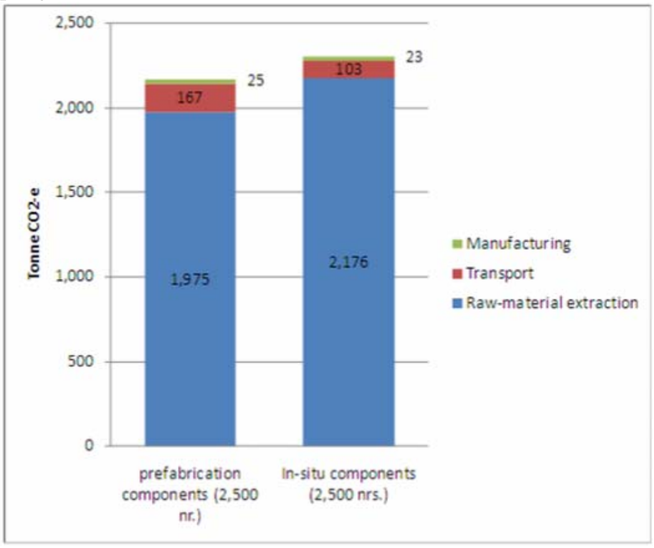


Fig. 11 The initial embodied carbon emission from the raw-material extraction to construction site for production of the 2,500 numbers of in-situ elements for a public housing development in Kai Tak area

Fig. 12 shows the breakdown of carbon emissions for prefabricated elements across the raw-material extraction, transport from extraction to factory, factory prefabrication, and transport from factory to site. 91% of the carbon emission (2,019 tonnes CO2-e) comes from raw-material extraction. 1% of carbon emission (25 tonnes CO2-e) comes from prefabrication-factory manufacturing. 8% of carbon emission (167 tonne CO2-e) comes from transportation (transports from raw-material extraction to factory and transports from factory to site). Raw-material extraction and prefabrication manufacturing contributed 92% of the carbon emissions. Transportation only contributed 8% of the indirect emissions. For process improvement, raw-material extraction drives the carbon emission for prefabricated elements.

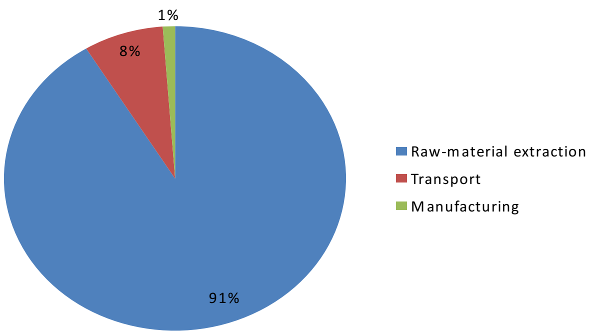


Fig. 12 The breakdown of carbon emissions for prefabricated elements across the raw-material extraction, transport from extraction to factory, factory prefabrication, and transport from factory to site for production of the 2,500 numbers of in-situ elements for a public housing development in Kai Tak area

*A. Carbon footprint of raw-material extraction*

Compared with the carbon emission of the prefabricated elements with the in-situ elements, the carbon saving comes from raw-material extraction. It is because prefabricated elements adopt reusable steel formwork. As per the information of factory, one set of steel formwork will use 36 times in the construction site in Kai Tak area. Approximately 69 sets of steel formwork will be required.

On the other hand, the hypothesis in-situ elements would use large amounts of sawn formworks. One set of sawn formwork can only reuse 6 times. For the same 2,500 numbers of components produced in the production period, approximately 416 sets of sawn formwork will be required. Therefore, for the same numbers of 2,500 numbers of components, an addition of 347 sets of formwork would be required. 200 tonne more initial embodied carbon emission would emit during raw-material extraction and manufacturing of the formwork. It is equivalent to the carbon absorption of 8,696 numbers of trees per year.

*B. Carbon footprint of factory manufacturing*

As explained in session 6.1.5, electricity in Shenzhen or most of China electricity is based on coal-fired (almost 74%), would have higher global warming potential. Prefabrication manufacturing of prefabrication elements will have 2 tonne more carbon emissions than hypothesis in-situ construction of the 2,500 elements. It is equivalent to the carbon absorption of 87 numbers of trees per year.

*C. Carbon footprint of transportation*

Trucks were used to transport raw-materials and prefabrication elements to factory (and to site). Parts of raw-materials for prefabrication elements are sourced from Hong Kong. The raw-materials will travel from Hong Kong to Shenzhen and Shenzhen to Hong Kong again. The travel distance is slightly longer than in-situ construction. The transport distance is more direct if hypothesis in-situ construction uses the same local raw-materials. Therefore, construction of the 2,500 numbers of prefabrication elements on-site would have 56 tonne less transportation carbon emissions than prefabrication elements. It is equivalent to the carbon absorption of 2,435 numbers of trees per year.

*D. Carbon Reduction from Prefabrication Elements*

Although prefabrication elements emit 58 tonne more carbon emission (equivalence of the carbon absorption of 2,521 trees per year) during transportation and factory-manufacturing stage, Prefabrication elements reduces overall 134 tonne carbon emission from "cradle to site" – raw-material extraction, transportation and factor manufacturing as prefabricated elements reduce formwork at the raw-material extraction. It is equivalent of the carbon absorption of 5,826 numbers of trees per year.

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*E. Expected Reduction of Embodied Carbon Emissions for Prefabricated Elements for the Construction Site in Kai Tak area*

For the construction site in Kai Tak area, there will be a total of 23,653 numbers of prefabricated elements for the six housing blocks. The project is under construction. Until the completion, all the data of prefabrication elements can be collected from factory.

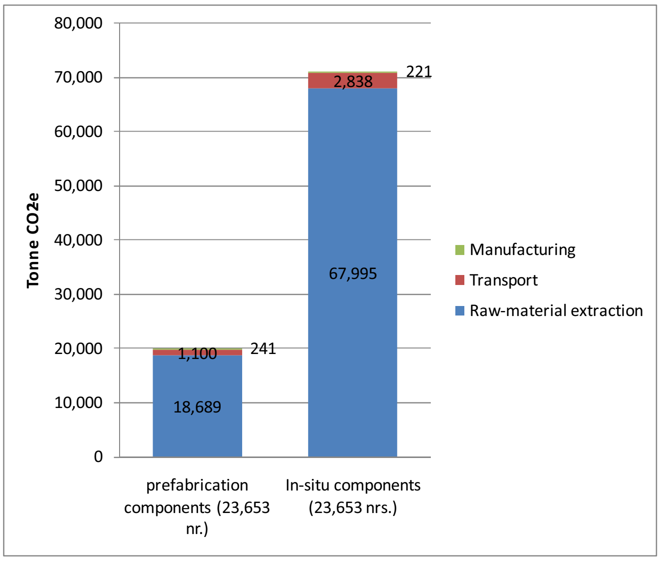


Fig. 13 The initial embodied carbon emission from the raw-material extraction to construction site for production of the 23,653 numbers of in-situ elements for a public housing development in Kai Tak area

At this moment, we can estimate the total initial embodied carbon emissions based on the factory data for the production period for April by pro-rata. The total initial embodied carbon emission is 20,446 tonne CO2-e. Compare with hypothesis in-situ elements, for the same numbers of 23,653 numbers of elements, 3,285 more sets of formwork would be required. 49,306 tonne more initial embodied carbon emission would emit during raw-material extraction and manufacturing of the formwork. It is equivalent to the carbon absorption of 2,143,739 numbers of trees per year. The transport of the additional 3285 sets of formworks would increase carbon emission by 1,738 tonne CO2-e. Prefabricated elements reduce 51,025 tonne of carbon emissions from the hypothesis in-situ construction of elements for the construction site in Kai Tak area (72% less). It is equivalent to the carbon absorption of 2,218,478 numbers of trees per year.

## V. Conclusions

This report takes account of the carbon emissions from prefabrication elements of Kai Tak construction site which comprises of prefabrication elements at April production period and expected carbon emissions for the whole Kai Tak construction site.

Most of the carbon savings of prefabrication elements (2,500 nr.) come from raw-material extraction. Increase of carbon emission occurs at transportation and prefabrication factory manufacturing for prefabrication elements (2,500 nr.). It is because parts of raw-materials for prefabrication elements were sourced from Hong Kong. The raw-materials will travel from Hong Kong to Shenzhen and Shenzhen to Hong Kong again. The travel distance is slightly longer than in-situ construction. It increases the transport carbon emissions. On the other hand, electricity in Shenzhen or most of China electricity is based on coal-fired (almost 74%). The prefabrication plan produced in Shenzhen utilizing China's electricity would have higher global warming potential. It increases the carbon footprint of prefabrication factory manufacturing.

Housing projects can further reduce the carbon emissions for prefabrication elements (2,500 nr.). On factory manufacturing, China electricity using the high global warming potential can be reduced through applying renewable energy and low emission fuel, such as biodiesel. On transportation, fuel with low carbon emission can reduce the transport carbon reduction vehicle with higher energy efficiency can also reduce carbon emission. Low emission carbon materials could reduce the carbon emission during the raw-material extraction. For prefabrication elements, cement and rebar contributes 32.4% and 25.6% of the carbon emission. Pulverized Fly Ash (PFA) might use to substitute part of the cement to reduce the carbon emission. However, PFA would increase the radon emanation rate of concrete (Yu, 1994). Steel rebar and steel formwork contributed 38% of the raw-material extraction carbon footprint. Recycle or reuse steel from previous projects could reduce the carbon emission of raw-material extraction.Prefabrication elements can reduce construction waste as well as greenhouse gas emissions. For a typical residential estate of public housing comprised of six 40-storey high blocks, 23,653 numbers of prefabrication elements can reduce 71.8% of the greenhouse gas emission compared with in-situ elements. Prefabrication element is a low carbon and low-waste solution although improvement can be introduced to further reduce the transportation and manufacturing carbon emission of prefabrication elements.

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## References

[1] Department for Environment Food and Rural Affairs, *2008 Guidelines to DEFRA's GHG Conversion Factors: Methodology Paper for Transport Emission Factors, London, UK,* Department for Environment Food and Rural Affairs, 2008.

[2] Environmental Protection Department and the Electrical and Mechanical Services Department. *Guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong*. Hong Kong SAR, China, 2010.

[3] Environmental Protection Department, *An Overview of Challenges for Waste Reduction and Management in Hong Kong*. Hong Kong SAR, China, 2011.

[4] Yu, K. *Radon emanation from concrete with pulverized fuel ash (PFA).* Building and Environment Volume 29, Issue 4, October 1994, 545-547.
[5] Beer, T., Grant, T., & Campbell, P. K. The greenhouse and air quality emissions of biodiesel blends in Australia. Victoria: CSIRO, 2007.
[6] Environment Bureau, HKSAR Government. Hong Kong's Climate Change Strategy and Action Agenda - Consultation Document. Hong Kong.: Environment Bureau, HKSAR Government, 2011.
[7] Promethium Carbon (Pty) Ltd. (2010). Carbon Footprint Report - Financial and Calendar Year 2009. Gold Fields.
[8] T.Y. Chen, J. B. (2001). Analysis of embodied energy use in the residential building of Hong Kong. Energy (26), 323-340.
[9] The Hong Kong Green Building Council; BEAM Society. (April 2010). BEAM Plus New Buildings Version 1.1. Hong Kong.
[10] Tinjian University. (2010). Global Warming Potential of China electricity emission. Germany: Global Emission Model for Integrated Systems.
[11] Wong, F., & Amato, A. (Dec 2006). Operational Model For A Combined Life Cycle Assessment (LCA) / Life Cycle Costing (LCC) Study For Office Of Swire Guangzhou Taikoo Hui Project. 2nd Mega-Cities International Conference 2006. Guangzhou, China.

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