BENCHMARKING OF THE HEALTH PERFORMANCE OF RESIDENTIAL BUILDINGS FOR A COMBINED LIFE CYCLE ASSESSMENT, LIFE CYCLE COSTING AND HEALTH IMPACT ASSESSMENT TOOL FOR PUBLIC HOUSING IN HONG KONG

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Summary

In 2005, a consortium comprising of thegreenroom, The University of Hong Kong, Davis Langdon & Seah Management Ltd., and the Business Environment Council completed a combined Life Cycle Assessment/Life Cycle Costing Study of a public rental New Harmony Block for the Hong Kong Housing Authority. The decision making tool measured the financial implications and ten environmental impacts of selecting 110 alternative building materials from the standard specification. The results showed that NHB block generated 1.54 HKE-points/CFA and cost HK$18040.46/CFA (US$2313.08/CFA) for the whole 55-year building life-cycle. If Ordinary Portland Cement block partition is changed to gypsum partition, the environmental impacts and the cost would increase by 0.26% and 0.07%, respectively. The decision-making tool assessed environmental and economic sustainability but did not assess the health advantages/disadvantages from alternative materials. To test the possibility of a health assessment, we identified three quantitative health indicators suitable for integration to the LCA and LCC tool: 1) risk-of-illness 2) burden of diseases in DALYs and 3) medical cost. This paper defines the health benchmark for existing residential building blocks in HK and it indicates the total cancer burden of residential building blocks with the three health indicators. The paper will demonstrate a three-tier decision-making process for health, environmental and cost performance with the three indicators and the health benchmark of a typical HK residential building. The final tool will assess the environmental, economic and health performance of housing developments.

1. Introduction – A Combined LCA and LCC Assessment Tool for HK Public Housing

In 2005, a combined Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) building assessment tool for Hong Kong Housing Authority (HKHA) was completed by thegreenroom, The University of Hong Kong, Davis Landon & Seah Management Ltd., and the Business Environmental Council in collaboration with Building Research Establishment (BRE), UK. The building in assessment was the New Harmony Block (Option 2) (NHB), a 40-storey concrete-framed residential building for public-rental that accommodates a total of 3,196 individuals (fig. 1).

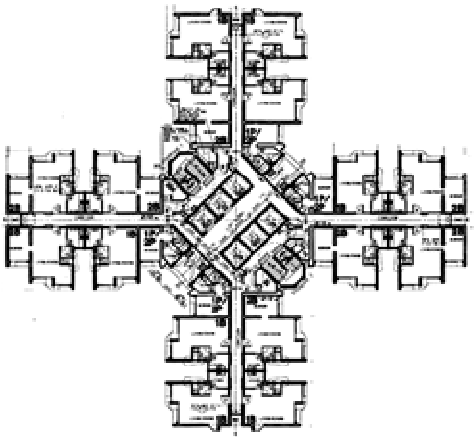

Figure 1 Typical floor plan (left) and the appearance (right) of the New Harmony Block (Option 2)

The goal of the combined tool was to measure the following ten environmental impacts and determine the financial implication of selecting 110 alternative building-materials under standard HKHA specification in the whole life cycle perspective, including (1) raw material extraction, (2) building material manufacturing, (3) transportation, (4) construction, (5) building operation, (6) repair and maintenance, and (7) disposal (Amato et al., 2006):

1. Energy (MJ)
2. Resource depletion (kg)
3. Water consumption (m^3)
4. Waste (kg)
5. Climate change (kg CO_2 eq.)
6. Acid Rain (kg SO_2 eq.)
7. Photochemical smog (kg C_2H_2 eq.)
8. Ozone depletion (kg CFC-11 eq.)
9. Toxicity to humans (kg toxic eq.)
10. Toxicity to ecosystems (kg toxic eq.)

a) Capital cost (initial cost)
b) Recurring cost (operational cost; repair and maintenance cost), and
c) Demolition cost

The tool characterised[1], normalised[2] and weighted[3] the ten environmental impacts into a notional HK Environ-pt (HK E-pts), which was equivalent to the ten environmental impacts generated by one HK citizen annually. By means of HK E-pts and the money spent, architects and other building management professionals can quantitatively judge the environmental-friendliness and cost-effectiveness of alternative building materials from the building life-cycle point of view. For example, the alternation of ordinary Portland cement block with gypsum partition can reduce life-cycle environmental impacts of NHB by 0.26% HK E-pts and increase the life cycle costs by 0.07% (Amato et al., 2006). The existing tool did not assess the social sustainability, which could include the aspect of health, skill, ability, education and social-connection (Hart, 1999).

1.1 Quantitative Health Impact Assessment and Indicators Combined with LCA and LCC

Existing LCA and LCC tool can potentially integrate with a Health Impact Assessment (HIA) module to measure improvement or decline in disease burden brought about through the use of alternative materials. To allow such an assessment, the selection of health indicators sensitive to modification of building materials would be important in the whole process. Wong et al. (2006) tested the sensitivity of various health indicators and found three that can be used to measure the disease burden from building materials (see table 1).

Table 1 Three types of quantitative health indicators appropriate for measuring burden of diseases related to building materials (Wong et al., 2006)

	Types of health indicators	Example of measurement
1	Risk of illness or dying	Probability of have specified illness or incidence rate per 1,000 or 100,000 population
2	Positive and negative burden of disease	Disability Adjusted Life Years (DALY) which measures both Years of Life Lost (YLL) and Years Lived with Disability (YLD)
3	Externality cost	Medical or treatment cost for illness

This paper provides a measurement of the potential disease burden of a typical 40-storey high-rise residential building in Hong Kong. The result can act as a comparison benchmark for the combined LCA,

[1] Howard *et al.*, (1999) described characterization as: *"The purpose of this is to translate different inventory inputs (emissions) into directly comparable impact indicators. The characterization process follows international practices in the characterization of inventory data for their potency with the different impact categories."*

[2] Howard *et al.*, (1999) described normalisation as: *"The purpose is to express impact indicator data in a way that can be compared among impact categories. The procedures normalized the characterized results by dividing by selected reference values, which can be:*
- *The total emissions or resource use for region that may be local, regional or global*
- *The total emissions or resource use for an area on a per capita basis"*

[3] The ten environmental impacts were weighted for their local, regional and global importance as set up according to a series of HKHA workshops organised in 2002.

LCC and HIA tool for public housing. This paper will use (1) the selected health indicators, (2) the health benchmark of typical HK residential building, and (3) the combined LCA and LCC decision-making tool to measure the health implications, environmental impacts and economic implications from applying different alternative partition materials on NHB housing block and discuss the benefits and the drawbacks.

2. Object of Study – A Typical Residential Premise

A typical HK residential building built in the 1990s is a 40-sorey high concrete-framed building. It accommodates 320 residential flats including 240 three-bedroom units and 80 two-bedroom units. The building can lodge as many as 1100-1200 individuals, which is one-third the population of NHB.

Figure 2 Typical floor plan (left) and appearance (right) of a residential building

Table 2 summaries the local indoor contaminant concentration level of a typical HK residential building and provides comparison to the mean Volatile Organic Compounds (VOC) concentrations of non-industrial indoors in Japan, the Level 1 and Level 2 Indoor Air Quality (IAQ) objective of HK Environmental Protection Department (HKEPD), and the carcinogen classification of those indoor air contaminants by the standards of the International Agency for Research on Cancer (IARC) (Ho 1996; Lee et al. 2002; Azuma et al., 2006; Indoor Air Quality Group Management Group 1999). Under IARC classification, Group 1 agents are carcinogenic to humans, Group 2A agents are probably carcinogenic to humans, Group 2B are possibly carcinogenic to humans, and Group 3 agents are not classifiable as to their carcinogenity to humans (IARC, 2007). Most of the indoor contaminants found in HK residential indoors have been classified as probably/possibly carcinogenic to humans, while radon, benzene and formaldehyde are definitely known for their carcinogenicity to humans (IARC, 2007). Note that carcinogenicity is defined by the concentration level and the occupants' exposure time to the carcinogen. This study assesses the potential cancer risk of these contaminants.

To benchmark the burden of cancer from radon and VOC concentrations of residential indoors, we applied the most updated epidemiological data from USEPA. Particularly, the data on radon was based on the cohort study based on the latest epidemiological follow-up of 68,000 underground miners (National Research Council, 1999). WHO (2000) considerers the epidemiological study on miners adjusted to residential context as the most reliable data for application to public health concerns.

We considered the hours of exposure data from different age groups to calculate the burden of disease Figure 3 shows the total hours of stay for HK dwellings (Chau et al., 2002) with the longest number of hours spent in bedrooms in HK residential buildings (7.9 to 9.8 hrs per day). Youth and elderly tended to stay longer in residential premises than other adults. Individuals of less than 18 years age and those above 60 years spend 57% and 68% of their time during weekdays at home, respectively. During weekends, the >60 age group could spend as long as 74% of their time indoors. Thus, the youth and elderly age occupants could have higher cancer potential from indoor contaminants than the adult group. According to our survey undertaken in a new town in HK, 12.4% of the population were smokers; 14% of the population was less than 15 ago old 30% was in the age group of 15-34; 44.3% was 35-64; and, 11.8% was higher than 64 age old living in a residential building.

Table 2 Radon and VOC concentration levels of HK residential dwellings, non-industrial indoors in Japan compared with the EPD Level 1 and Level 2 IAQ objective and International Agency for Research on Cancer classification of carcinogenicity to humans (Ho 1996; Lee et al. 2002; Azuma et al., 2006; HKEPD 1999; IARC, 2007)

			HK	Japan	HKEPD
		IARC classification of carcinogenicity to humans	Living room [4]	non-industrial indoors measured from 1995-2004)[5]	IAQ objective [6]
Contaminants	**Units**	**Group**	**conc. range (mean)**	**mean conc.**	**Level 1, Level 2**
Radon (window close)	Bq/m^3	1	114	-	150, 200
Radon (window open)	Bq/m^3	1	92	-	150, 200
Benzene	ug/m^3	1	1.5-9.9 (4.7)	4.554	16.1
Toluene	ug/m^3	3	26-77.2 (52.1)	80.443	1092.0
m, p-xylene	ug/m^3	3	1.6-7.7 (3.9)	-	1447.0
o-xylene	ug/m^3	3	1-10.8 (4.5)	-	Xylene (o-, m-, p-isomer)
Ethylbenzene	ug/m^3	2B	N.D.-4.7 (2.6)	17.977	1447.0
1,3,5-trimethylbezene	ug/m^3	Nil	N.D.-4.5 (1.8)	4.71	
Trichloroethylene	ug/m^3	2A	N.D.-2.1 (1.8)	3.045	770.0
Tetrachloroethylene	ug/m^3	2A	N.D.-4.4 (2.5)	17.977	250.0
1,4-Dichlorobenzene	ug/m^3	2B	1.2-4.3 (2.6)	114.149	200.0
Chloroform	ug/m^3	2B	1.6-3.6 (2.6)	1.147	163.0
Methylene Chloride	ug/m^3	2B	6.8-10.2 (8.8)	9.842	
Formaldehyde	ug/m^3	1	3.2-20.1 (16.0)	46.91	30, 100

N.D. –Not detectable; 4 - **(Lee et al. 2002; Ho 1996); 5- (Azuma et al. 2006; 6 - (HKEPD, 1999)**

Table 3 Time activity pattern for different age group during Weekday and Weekend (Chau et al., 2002)

	6-18 age	**6-18 age**	**18-60 age**	**18-60 age**	**>60 age**	**>60 age**
	Weekday	**Weekend**	**Weekday**	**Weekend**	**Weekday**	**Weekend**
Indoors at home	**hr/day**	**hr/day**	**hr/day**	**hr/day**	**hr/day**	**hr/day**
Bedroom	8.63	9.83	7.92	9.06	8.13	8.38
Living/ dining room	3.83	4.01	3.10	4.20	4.81	5.60
Kitchen	0.41	0.31	0.81	1.01	2.25	2.52
Bathroom	0.88	1.03	0.97	1.08	1.15	1.15
Total hr at home	13.75	15.18	12.80	15.35	16.34	17.65

3. Results of a Health Benchmark Study on a Typical HK Residential Premise

According to the time activity pattern, the indoor and VOC concentrations found in a typical residential premise, the surveyed population mix, and the smoking prevalence of occupants, we calculate the health performance of a typical concrete-framed residential building if all occupants live for 30 years in the dwelling. The indicators were in terms of cancer risk, cancer DALYs and cancer treatment cost. Table 4 shows the health benchmark result. Nearly 96% of the cancer risk arises from lung cancer associated with the radon concentration of the concrete-framed building and smoking habits of occupants. The 2nd and 3rd hotspots were leukaemia risk caused by benzene and nasopharynx cancer caused by formaldehyde, respectively. These contaminants were associated with 2nd-hand smoking, outdoor air pollution, cooking combustion and off-gassing of building materials (Niu et al., 2001).

Table 4 The potential cancer risk of a typical HK residential building built in the 1990s if all occupants live for 30 years in the dwelling

Health Indicators	**Cancer Risk**
Risk of cancer per 1,000 people	2.6-2.7
Cancer DALYS per 1,000 people	78.56-79.85
Cancer treatment cost per 1,000 people (US$)	278,514-282,968

4. Result of Health Performance of New Harmony Block (Option 2)

After setting up the benchmark, we utilised the combined LCA and LCC decision-making tool, the health indicators and the health benchmark to assess the health performances from different partition materials for a typical public housing block. The assessment of a public housing block was based on real ventilation measurements, and the results of studies on the actual population mix, window operation patterns and real exposure survey. These data will be explained in more detail in future publications.

Figures 3 – 5 show the difference of cancer risk, DALYS and treatment cost per 1000 people between a typical public housing block and the health benchmark of a typical HK residential building. The public housing block has 5-6% lower cancer risk, less cancer DALYs and lower cancer treatment costs than the benchmark for a typical residential building in HK of all occupants live for 30 years in the dwellings. This is because public housing block has better cross-ventilation than a typical residential block which lack corridor windows and whose main doors are always closed due to security demands from occupants, resulting in reduced potential air circulation.

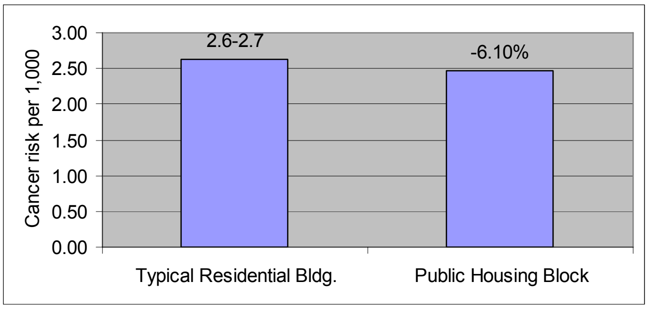

Figure 3 Cancer Risk per 1,000 people for a Public Housing Block and Health Benchmark

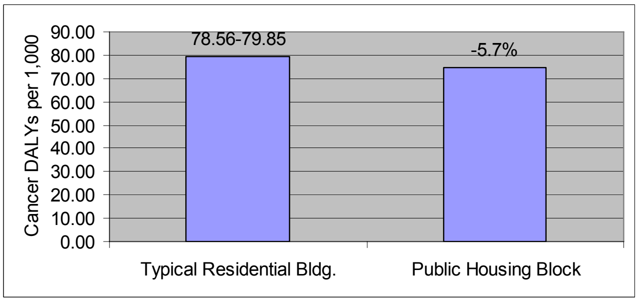

Figure 4 Cancer DALYs per 1,000 people for a Public Housing Block and Health Benchmark

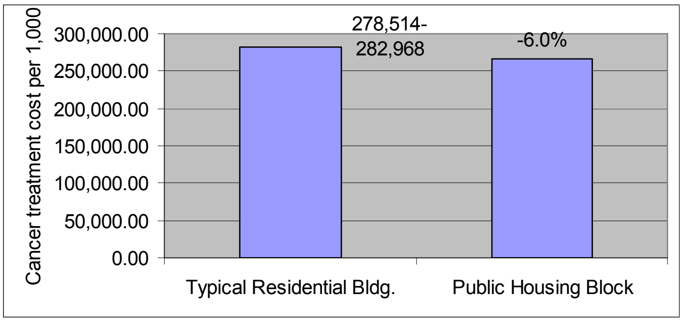

Figure 5 Cancer Treatment Cost (US$) per 1,000 people for a Public Housing Block and Health Benchmark

5. Alternative Study to Reduce Radon Cancer Risk from Partition Materials

Five alternative partition materials were tested by Mui (2005): PFA concrete block, lightweight concrete partition, gypsum partition, red brick partition and autoclave aerated concrete (AAC) block partition. These partition materials are made of soil or rock and they emit radon at different emanation rates as shown in Figure 6 (gathered from local literature by Mui 2005).

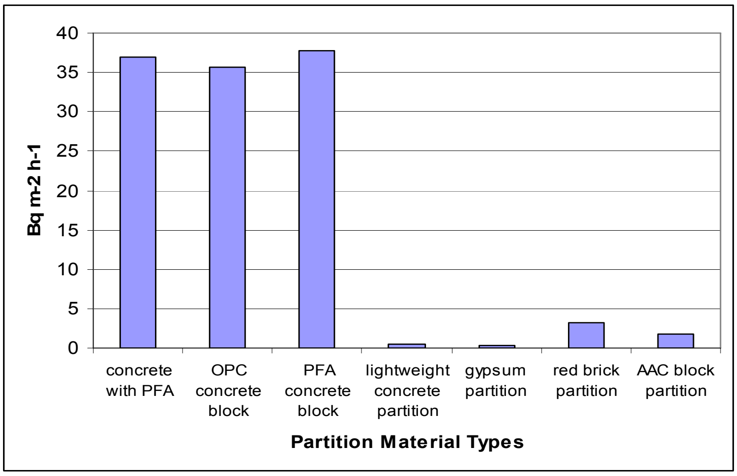

Figure 6 Radon Emanation Rate (Bq. m-2h-1) of different partition materials from local literature (Mui, 2005)

Some partition materials for example, gypsum partition, emit small amounts of carcinogenic VOCs. By applying the mass balance model and the VOC time decay pattern of building materials, the life-cycle environmental performance in terms of HK E-pts, life-cycle cost and the operational health improvement in terms of the three health indicators for a public housing block with gypsum partition are shown in Table 5. Gypsum partition increases the life-cycle environmental impacts by 0.26% and increases the life-cycle cost by 0.07%. Figures 6-8 show the cancer risk, cancer DALYs and cancer treatment cost per 1,000 people between health benchmark, the public housing block without any alternative materials and with gypsum partitions.

Table 5 Comparison of the life-cycle environmental impact and life-cycle cost between a public housing block without any alternative materials and a public housing block with gypsum partition

Case	Life Cycle Env. Impact (HK E-point per CFA)	Whole Life Cost (HK$ per CFA)
Base case with hollow concrete block	1.540	18040.5
Alternation from hollow-concrete block to gypsum partition	1.544 (+0.26%)	18053.1 (+0.07%)

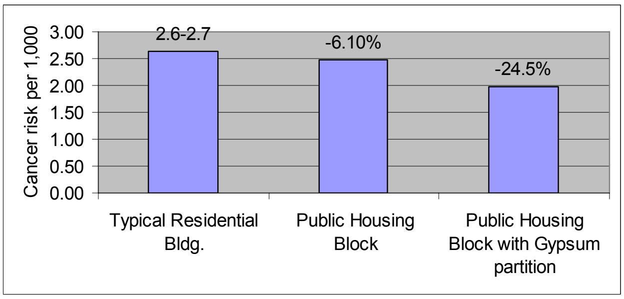

Figure 6 Cancer Risk per 1,000 people for a Public Housing Block and Health Benchmark and a Public Housing Block with Gypsum Partition

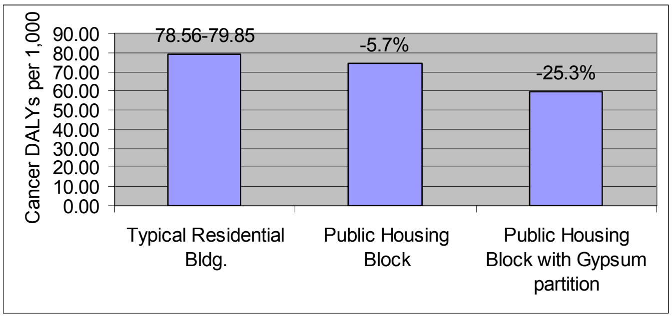

Figure 7 Cancer DALYs per 1,000 people for a Public Housing Block and Health Benchmark and a Public Housing Block with Gypsum Partition

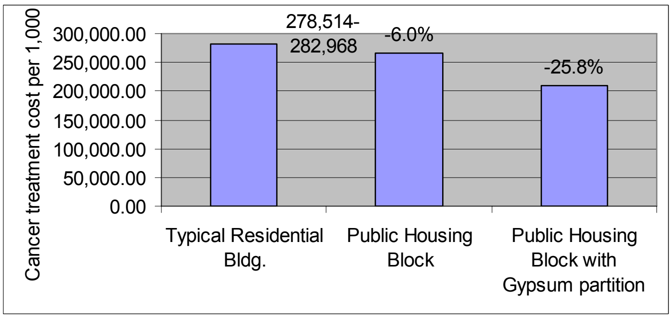

Figure 8 Cancer Treatment Cost (US$) per 1,000 people for a Public Housing Block and Health Benchmark and a Public Housing Block with Gypsum Partition

Compared to the benchmark for a typical HK residential building, a public housing block with gypsum partition can improve the health performance of the building during operation stage with 24.5% less cancer risk, 25.3% less cancer DALYs and 25.8% less cancer treatment cost. Although the gypsum partition increases the life-cycle environmental impacts and the life-cycle cost by about 0.3%, these costs are considered to be negligible in comparison to the greatly improved health performance by over 25% and reduced potential cancer treatment cost by 25.8%. In the long term, these can greatly reduce the burden on the society's health investment.

5. Conclusion

This paper demonstrates an example of the combined LCA, LCC and HIA decision making process. The combined LCA, LCC and HIA tools can potentially help decision makers to justify the environmental, economic and health performance of any building. This paper also measured the health, environmental and cost benefits from source control approach with gypsum partition.

Future publications will investigate the health, environmental and cost benefits from improvement on ventilation approaches and other alternative material applications. The future focus of our research will address the health burden of other life-cycle stages other that the 55-year building operation period included in this analysis. The final tool will assess environmental, economic and social sustainability of the whole building life-cycle and facilitate holistic decision-making for public housing.

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