SUSTAINABLE BUILDING, HONG KONG WETLAND PARK

Architectural Services Department (ArchSD)

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Abstract

This paper describes the design of the Hong Kong Wetland Park on the north-eastern edge of Tin Shui Wai (TSW) New Town, New Territories, Hong Kong. The Park is envisaged as a prime example of harmony with nature, environmental practice and sustainable development; unique to Hong Kong; seeking to provide equally for the very varied and potentially conflicting functions of conservation, tourism, education and recreation.

The paper also describes the approach in seeking to provide the very varied and potentially conflicting functions of conservation, tourism, education and recreation. Environmental issues have been tackled by a strong multi-disciplinary team to apply their diverse knowledge and skills to meeting the stringent requirements with an approach to every aspect of the project including site layout, hierarchy of intended site usage, building form, landscape and habitat creation, building services installations and the choice of materials.Innovative ideas such as energy saving with geothermal system for air-conditioning, recycled materials, materials from sustainable sources, reduction of water usage and reduction of generated waste, etc. have been utilized.

Introduction

The Hong Kong Wetland Park is on a 64 hectare site on the north-eastern edge of Tin Shui Wai (TSW) New Town, New Territories, Hong Kong. The site was originally envisaged as purely a conservation and ecological mitigation initiative between the urban areas and the Inner Deep Bay RAMSAR site and Mai Po Marshes to the North-east which was required as one of the conditions of the Town Planning Board approval to the development of the TSW Reserve Zone as the major second development phase of the TSW. However, the Visitor and Tourism Study for Hong Kong, commissioned by the Hong Kong Tourism Board, recommended that new tourist attractions and facilities should be developed to sustain the long-term growth of the tourism industry. The idea for the Wetland Park arose from this vision, building upon the existing ecological mitigation plans to create a major tourism, educational and community facility based around the ecological themes of wetland conservation.

Figure 1 Southern entrance of Phase 1 building with recycled granite as paving

1.0 Sustainable Building

The development is comprised of two phases. Phase 1 has been completed at the end of year 2000 as a small scale exhibition gallery and garden serving as an environmental and sustainable demonstration for the things to come and further elaborated in the Phase 2 development. These include the handling of the building envelope and the adoption of screens and louvers to maximize energy efficiency; the use of natural materials including timber, stone and oyster shells; reliance on natural ventilation and lighting wherever possible; a trial geothermal heat pump air-conditioning; and the extensive use of native wetland plant species, not commonly available in the Hong Kong nursery trade. The Phase 1 building is being conserved and converted into a Ticket Office when the Phase 2 Visitor Center opens in early 2006.

The Visitor Centre has an gross floor area of approximately 10,000m. It is sited close to the entrance of the site and the urban area. Thereafter a series of display gardens, exhibition ponds and recreated habitats lead progressively to the Satellite Building Discovery Centre, and beyond via a series of fixed and floating boardwalks to the bird hides and more remote outer habitat areas, closer to the RAMSAR site, where visitor number are expected to be much lower. The level of built form and intensity of usage diminishes as one moves further into the site, away from the urban development and towards the RAMSAR site, and the recreated natural habitats gradually predominate.

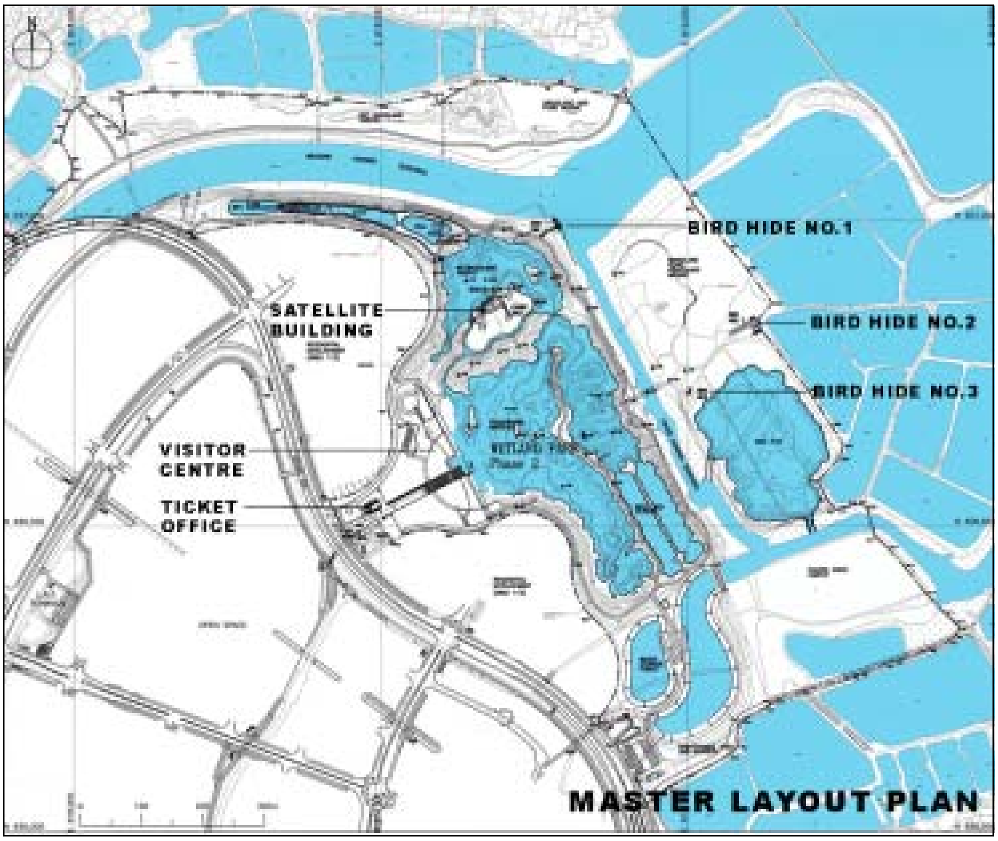

Figure 2 Master layout Plan

1.1 Visitor Centre

At the entrance plaza, the sound of water falling from an entrance water feature opposite the Ticket Office rejuvenates and welcomes visitors coming by car, coach or on foot from TSW town. The Phase 1 centre will be retained by converting its interiors and toilet layout and transforming it into a Ticket Office. Its original sustainable concepts will be maintained. On leaving the Ticket office, visitors can enjoy the view of an accessible green hill which hides the Visitor Centre below. The landscaped roof, as well as immediately announcing the environmental credentials of the scheme, is also instrumental in maximizing the energy efficiency of the building – the form of roof construction works with the careful orientation of the building to minimize solar gain. In addition, visitors may stroll up the gently sloping lawns of the roof to where a spectacular panorama of the surrounding wetland habitats will unfold before them. A water feature close to the Ticket Office feeds into a narrow stream course in the middle of a processional route with glazed canopy and recycled Chinese brick wall on the west of the processional route linking up the Ticket office and the Atrium of the Visitor Centre building mitigating the effects of solar gain on buildings.

Figure 3 Entrance plaza with a stream course leading into the Visitor Centre which is hidden underneath the leisurely lawn roof

The transition from internal gallery space to external demonstrations in the recreated wetland landscape is almost seamless, continuing the educational message of environmental concern and stewardship. As the visitor exits the building, a source of a rushing mountain stream, cascading over boulders down from the roof of the Visitor Centre will be found, in the first of a series of recreated habitat displays. The stream can be followed downhill through all stages of its natural life cycle until it slowly winds through the delta and empties into a freshwater pond close to the Satellite Building Discovery Centre.

1.1.1 Sustainable Teachings

Sustainable buildings must convey their design approach and detailing to the next generation, in order to encourage people to become sustainable minded. Deriving from the exceptional potential of the wetland park, educational interpretive programmes are being developed for use both by school parties and other visitors. For example, visitors can pond-dip to investigate the life forms commonly found in water bodies; learn how the Wetland Park is managed and the water levels manipulated by simple mechanical devices; and discover a wide range of wetland agricultural practices that have been an important way of life historically for the people of Hong Kong and China.

Figure 4 Atrium with skylight giving natural lighting, Chinese recycled brick wall on the west which extended from the Ticket office and the stream course in the middle of the Atrium which leads to the wetland beyond

2.0 Construction Materials and Methods

Great care has been taken throughout the construction process from site formation to piling to superstructure works to minimize any potentially adverse ecological impacts. As far as possible, all excavated materials are to be reused on site, whereas the use of hoardings, formwork and other temporary works will be carefully controlled. Natural clay materials are to be used to waterproof lakes and ponds.

For the site formation work, approximately 5000 tonnes of grade 200 recycled crushed concrete was used. At the piling work, approximately 1000 tonnes of grade 200 recycled crushed concrete was used. For the superstructure work, a total of 4900 tonnes of grade 200 and 4400tonees of 40mm size crushed concrete was used as sub-base, hardcore and fill materials for the Visitor Centre and external works.

2.1 Sustainability and Recycled Materials

In Hong Kong, disposal of construction and demolition (C&D) waste materials generated from construction activities is always a problem. Lifespan of public fills is depleting much faster than planned. Solid waste disposal has become a social problem in Hong Kong in recent years due to the public outcry of protecting the water line in the harbour. In support of the Government's initiative of reducing C&D wastes, ArchSD has participated a study to look into the feasibility of using recycled aggregates in concrete works in order to reduce C&D wastes.

2.2 Use of grade 200 crushed concrete

For the site formation work, approximately 5000 tonnes of grade 200 recycled crushed concrete was used. At the piling work, approximately 1000 tonnes of grade 200 recycled crushed concrete was used. For the superstructure work, a total of 4900 tonnes of grade 200 and 4400tonees of 40mm size crushed concrete was used as sub-base, hardcore and fill materials for the Visitor Centre and external works.

2.3 Use of recycled coarse aggregates in ready mixed concrete

The Wetland Park and Visitor Centre is the first pilot project of the Architectural Services Department to use recycled aggregates in concrete, among many environmental objectives consistent with the theme of the project. This is also the first building in Hong Kong with an extensive use of concrete incorporating recycled aggregates. The quantities of 20mm size recycled aggregates obtained from the recycling plant at Tuen Mun Area 38 is about 5600 tonnes.

The quantities of concrete with recycled aggregates used and their locations are given in the attached table. It may be noted that the cement content of 380 kg/m^3 for the grade 35D/20 with 75mm slump is rather high because both the contractor and the ready mixed concrete supplier are cautious, and hence a greater design margin is adopted than is normally the case. The use of concrete with recycled aggregates is in accordance with the Particular Specification promulgated under WBTC No. 12/2002.

There were some problems in controlling the workability at the start because of the uncertainties in the moisture content in the aggregates, and the amount of water going to be absorbed. At the recycling plant the aggregates were kept being sprayed with water as a dust suppression measure, but in so doing only the top portion of the stockpile remained wet. By the time that they were transported to the batching plant and then exposed to the atmosphere, there was further change in moisture content.

The saturated surface dry condition stipulated in the Particular Specification was difficult to achieve in practice. Spraying the aggregates with water before batching would make them excessively wet, and as an alternative, mist spraying was adopted. It was only after a number of trials coupled with the use of an admixture that workability was finally brought under control. The admixture chosen was a high performance water reduction and set retarding admixture, formulated with lignosulphonates and modified polymer, normally used at a dosage of 0.2 to 0.7ml per 100 kg of cement.

Since commencement of construction in April 2003, the slump for Grade 35D/20 has remained within the 110 mm to 130 mm range upon completion of batching, and the slump measured upon arrival at the site after a journey of about 30 minutes was between 75 mm and 95 mm. As the concrete was compacted in its final position within 30 minutes, there was little problem encountered although the concretors have mentioned about the last batch of concrete discharged from the mixer being a bit tougher to work with.

Feedback from the contractor is that concrete containing 20% recycled aggregates is little different from normal concrete. So far the 28-day cube strength stays between 35.0 and 60.5 Mpa with an average of 49.2 Mpa and the standard deviation is maintained at 5.2 Mpa.

Apart from some minor cracks due to the restraint of the previous pour in the retaining walls, no cracks attributed to shrinkage have been reported. Carbonation test was carried out with concrete over two years old and there is no traceable carbonation depth.

Sample specimens of the concrete have been collected for shrinkage measurements and determination of elastic modulus. Another sets have also been sent for creep measurements. The results are given in Appendix A, B & C.

In summary, the quality of concrete with recycled aggregates with respect to strength, workability, Young's modulus, creep, shrinkage and the durability characteristic such as carbonation are very comparable with concrete containing ordinary crush rock aggregates.

The total amount of structural concrete used in Wetland Park project containing the recycled aggregates or PFA is about 75% of the total concrete volume.

2.4 Pulverised Fuel Ash (PFA)

PFA is used as partial cement replacement for all concrete in watertight construction. Concrete mix containing PFA has been specified in the Visitor Centre lawn roof construction in order to reduce shrinkage and thermal cracking. Thus, other than the waterproofing membrane, the concrete structure acts as a second defense barrier.

2.5 Construction Methods

Piling work has already been completed and the main building contract commenced in April 2003. This will be followed by the exhibit installation work before overall completion scheduled for early 2006.

Jacking machines and hydraulic hammers are used in the driven steel H-piles contract to mitigate noise and air pollution in the foundation works.

To avoid any contamination to the existing lakes and water bodies during construction, at ArchSD's request, CEDD have installed a double sheet pile barrier to segregate the Visitor Centre from the water, which will be removed at the end of the contract. In addition, a clay bund has been installed to protect the satellite building area particularly during the excavation of its footings, whereas ArchSD are currently working with their main contractor on a method statement to develop a portable coffer dam system to allow construction of the boardwalks to proceed with the minimum environmental disruption, avoiding the need to drain any of the lakes whilst avoiding any incidence of pollution.

To avoid any contamination to the existing lakes and water bodies during construction, a double sheet pile barrier was installed to segregate the Visitor Centre from the water, which is removed at the end of the contract. In addition, a clay bund has been installed to protect the Satellite Building Discovery Centre area particularly during the excavation of its footings. A portable coffer dam system was used to allow construction of the boardwalks to proceed with the minimum environmental disruption, avoiding the need to drain any of the lakes whilst avoiding any incidence of pollution. Clay bunds have been laid at ends of an existing tidal channel to segregate the construction of a floating boardwalk from the channel to avoid contamination.

3.0 Air-conditioning System

The most commonly employed refrigeration systems for air-conditioning installations in Hong Kong are either air-cooled or water-cooled. The heat energy generated by these systems is usually dissipated either directly into the atmosphere, or into a watercourse, or into a re-circulating water system and then to the atmosphere. These arrangements are not only waste of energy but would also induce adverse effects to the environment. In addition, noisy refrigeration plants such as air-cooled condenser or cooling tower are often visible from the outside of a building that sometimes would require expensive acoustical and architectural treatments.

ArchSD has designed a Geothermal Heat Pump Air-conditioning (GHP A/C) System in the Hong Kong International Wetland Park project in Tin Shui Wai, New Territory, Hong Kong. In this system, the wetland serves as a large heat sink and there is no direct rejection of waste heat into the atmosphere. In summertime, the condensing water from the A/C units is used for heating and humidity control. Surplus heat energy if any, will be rejected to the ground via water pipes buried underground. In wintertime, heat is extracted from the ground via the water pipes by heat pumps to provide heating for the building. There is no visible noisy A/C plant outside the building and the project architect also has greater flexibility in the design of the building façades.

It is believed that this GHP A/C system is the first of its kind in the territory.

3.1. What is Geothermal Heat Pump (GHP) A/C System?

In simple term, a Geothermal Heat Pump (GHP) A/C System exchanges heat with the ground. It makes use of the ground as a source of heat when heating is needed and rejects heat into the ground when cooling is required. The ground thus serves as a large heat sink. In fact, it was stated that the ground is a better heat source or heat sink than the ambient air as its temperature swing is more moderate than the ambient air (James E. Bose *et al*., 2002). Therefore, it allows a steady operation of the heat pump A/C system which would prolong the lifespan of the equipment. Besides, the ground temperature is generally cooler than the ambient air in summertime and relatively warmer in winter which enables the A/C equipment to be operated at a higher efficiency. Substantial saving in the running cost of the air-conditioning system can thus be achieved by the proper design and application of the GHP A/C system.

A GHP A/C system may consist heat pump(s) with or without reverse cycle function, water-cooled condensing unit(s) and ground source heat exchanger(s). The ground source heat exchanger is a series of underground or underwater pipes that either extracts or rejects heat to the ground or water. A GHP A/C system can provide year round cooling and heating in a manner similar to conventional A/C systems.

3.2. Geothermal Heat Pump Air-conditioning System

The total installed cooling capacity of the air-conditioning plant for the Visitor Centre is 710 TR (2500kW) but due to high occupancy diversity, the required peak geothermal heat dissipation load is only 390TR (1370kW). The GHP A/C System employed at the Visitor Centre is a hybrid system. It consists of a Ground-Coupled Heat Pump (GCHP) A/C system with vertical pipe loops plus an additional Aqua-therm Heat Exchanger for emergency backup.

An accurate knowledge of the thermal properties of the ground is needed when designing the closed-loop geothermal heat exchanger as this will affect the depth and number of boreholes required (Chad A. Kavanaugh, Stephen P., 2002). A field test was therefore conducted to ascertain the ground thermal conductivity and also to collect information on the drilling conditions of the site.

The geothermal closed-loop heat exchanger consists of 468 numbers 32mm diameter flow and return HDPE pipes of 50m (approx.) long inserted into boreholes and embedded in bentonite clay and cement grouting for better conductivity. The boreholes are placed at 4m center to center so as to ensure that the heat dissipation capacity of each borehole would not be affected by one another. These individual pipes are then jointed together in groups of 8 to 12 to the main headers of the geothermal closed-loop heat exchanger. The whole heat exchanger is sub-divided into 12 headers and each header connects to approximately 40 nos. vertical geothermal pipes. This design is to minimize the amount of trench works as well as to ensure that in case any one part of the geothermal heat exchanger needs to be shut down for repair or maintenance work, it will only affect 8% of the total A/C capacity. Furthermore, there is an additional 350 kW of aqua-therm heat exchanger embedded in an artificial lake of the Park to provide further emergency backup or for night use.

In this system, considerable energy is required for circulating the condensing water through the lengthy pipework of the geothermal closed-loop heat exchanger (although polyethylene pipes have friction loss only 25% of the commonly used black steel pipes). In order to reduce the pump energy, the total A/C load is split among small zone A/C units rather than having a large central chiller or heating plant. This is because for large central plant, it is necessary to maintain a minimum flow of condensing water to circulate through the chillers or heat pumps whilst for small A/C units, the condensing water flow rate can be varied according to the actual number of condensing units in use. As for each AHU, there are two circulation pumps (one duty and one standby) of its own for the reheat coil which claims heat from the condensing water for summer humidity control.

The A/C system saves up to 25% of energy over conventional cooling tower. Approximately 468 numbers 32mm diameter flow and return high-density polyethylene (HDPE) pipes are inserted into the ground at 50m depth embedded in bentonite clay and cement grouting for heat exchange with the constant underground temperature giving approximately 390 tonnes of air-conditioning. The lake water has also been utilized for a back up Aqua loop system by means of heat dissipation at a water feature and storage pond with the capacity of delivering a total of 144 tones of air-conditioning. This eliminates visible and noisy heat dissipation air-conditioning equipment, reduces external louvers and precludes direct heat injection to the environment which is found to be favorable and suitable to the wetland park setting.

3.3 Financial Considerations

The initial cost, energy cost as well as life cycle cost analysis of employing GHP A/C System were compared to that of air-cooled chillers system and water-cooled chillers with cooling towers. Details of these analysis are as shown in Appendix I, II, III & IV.

From the analysis, the GHP A/C system basically has the highest initial cost among the three A/C systems. However, due to savings in builder's work as well as recurrent energy costs, a pay back period of less than 3 years in comparing with air-cooled system and less than 10 years in comparing with cooling tower system can be achieved (as shown in Appendix III). Furthermore, as the HDFE pipes used in the geothermal heat exchangers are very durable material with an expected working life of at least 50 years as guaranteed by the manufacturer, an overall life cycle saving of more than HK$39 millions in comparing with air-cooled system and more than HK$21 millions in comparing with cooling tower system can be achieved in a 50 years period (as shown in Appendix IV).

4.0 Satellite Building and Bird Hides

The Satellite Building has been designed with a similar sustainable approach to the Ticket Office. In addition it relies entirely on natural ventilation by means of high ceiling and high level windows for dissipation of heat. Solar gain is also minimized by careful use of sustainable timber louvers. The flat roof has been designed to collect rain water for flushing purposes.

There are three Bird Hides located at different areas of the site. These outlying bird hides are designed with skylights and double-skin sustainable timber louvers to maximize natural ventilation. User comfort is further enhanced by solar panel powered oscillating fans. Beyond the Satellite Building, timber boardwalks lead out across the lakes into the Outer zone of increasingly natural landscape and lower key development, characterized by timber bird hides, boardwalks and nature trails.

Figure 5 Western entrance of Satellite Building Discovery Centre connected with timber boardwalk extending over Exhibition pond; Southern entrance of Bird Hide 1 with timber boardwalk in the foreground

5.0. Implemented environmental and sustainable concepts

5.1 Major Green concepts

Integrated with the natural setting of a 64 hectare park, the structures of the buildings are purposely designed with landscape roof, timber cladding and multiple layers of shades. The Visitor Centre has three major Galleries, Resource Centre, Office, Café, Shop, Play area and Toilets. In the external area, the Satellite Building and three Bird Hides. All of which have their unique functions conveying wetland messages. There are also 10 major green concepts embedded in the development as summarized in the following aspects.

5.1.1 Low overall thermal transfer value (OTTV)

Green Roof and orientation of the building allow the Visitor Centre envelope to achieve energy efficiency performance of approximately OTTV 16W/m^2.

5.1.2 Geothermal heat pump hybrid air-conditioning system

With the sizeable land of the park, a Geothermal Heat Pump Hybrid Air-conditioning system is adopted at the Visitor Centre.

5.1.3 Natural lighting and ventilation

Natural lighting by means of skylight at Atrium (north light) and external toilets. External artificial lighting is minimized to reduce power consumption. Natural ventilation is implemented by means of high level windows at the Satellite Building, double layer of louvers and vented skylights at External Toilets for energy saving. Solar panels, delivering a maximum of 200W of power, drive fans at Bird Hides.

5.1.4 Ramp access

Circulation ramps are built throughout G/F and 1/F galleries at the Visitor Centre to cater for disabled visitors and minimize the use of mechanical lifts.

5.1.5 Minimized water consumption

Low capacity, 6-liter water closets are used to reduce water consumption at all toilets. Satellite Building has been designed to collect rainwater for flushing. Recycling of the lake water for a water feature saves water consumption. Automatic irrigation is provided to aid soft landscape establishment and maintenance but only used at night time to reduce evaporation and consumption.

5.1.6 Re-cycled brick wall and fenders

Re-cycled Chinese brick from demolished traditional Chinese village houses, and collected by Antiques and Monuments Office, has been used as a brick wall on the south aspect of the Visitor Centre & Ticket Office to mitigate the effects of solar gain to the building. Fenders collected from Victoria harbour piers have been re-used in the freshwater marshes to serve as resting posts for wildlife.

5.1.7 Shading by timber screens

Sustainable timber from identified renewable sources is used throughout the whole project as vertical and horizontal louvers to provide shades for buildings and external landscape works.

5.1.8 Recycled aggregates and PFA

A total of 15,300 tonnes of recycled aggregates has been used as sub-base, hardcore and fill materials in the development together with 5600 tonnes of recycled coarse aggregates in the structural concrete. The majority of the recycled aggregates are from a nearby recycling plant. The total amount of structural concrete used containing recycled aggregates or PFA as partial cement replacement amounts to about 75% of the total concrete volume.

5.1.9 Re-use of existing materials

Existing materials at the Phase 1 site, including aluminium wetland habitat sculptures, recycled granite paving from the Hong Kong Police Headquarter’s wall, recycled Chinese bricks from demolition of old Chinese Village houses and re-used oyster shells from nearby Lau Fan Shan oyster farm would be reused in the Phase 2 works. The existing Phase 1 Visitor Center would be converted into a new Ticket Office. All existing trees and many other plants from the Phase 1 site will be retained or transplanted within the Phase 2 site.

5.1.10 Soft landscape species

Predominantly native plant species which require less maintenance and water consumption are used for landscaping work.

6.0 Conclusion

The use of Sustainable and Recycled materials, innovative Geothermal Heat Pump Air-conditioning system, maximize use of natural lighting and ventilation etc. which are all part of the sustainable ideas in the building and no doubt, this would have benefits both financially and environmentally.

On opening in early 2006, the Hong Kong Wetland Park will represent a showcase of sustainability and environmental consciousness in building harmony with nature, in terms of architectural, structural, building services and landscape design. It will satisfy its potentially conflicting objectives in order to provide a world class tourist attraction and also a major conservation, educational and recreational resource.

To build sustainable buildings, it requires strong collaboration efforts from the design team, client and contractors. From determining the project brief to conceptual design, to detail drawings, to construction work, to completion of the development and running of the building; all these require a fresh and open mind for sustainable thinking. The usual mind-set on construction which is very valuable but sometimes have to think further for our generation to come. In building the Wetland Park, we had a very steep learning curve and to be frank we are still learning.

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Appendix A

Concrete Mixed Data and Test Results

Contract Title	Construction of International Wetland Park and Visitor Centre, at Tin Shui Wai, New Territories, - Phase 2			
Planned amount of recycled aggregate concrete	4570M^3	6751M^3	1355M^3	1421M^3
Concrete Grade	Grade 35D/20	Grade 35D/20	Grade 20D/20	Grade 10D/20
Area of Usage	Ground slabs and beams and perimeter wall	External works including retaining walls	Mass concrete and minor concrete works	Concrete blinding
RMC Supplier	Multi-Way Industries Ltd. – Yick Yuen Plant, Lot 1825 in DD130 Yick Yuen, Tuen Mun, Yuen Long, N.T.			
Travelling distance	~10 km from ready mix concrete depot to site			
Time between cement added and arrival on site	Average 30 minutes			
Supply Date	May 2003 – June 2004			
Concrete mix data Natural aggregates 20mm Recycled aggregates 20mm Fine aggregates 10mm Fines Cement Free water W/C ratio A/C ratio Admixture	For Grade 35D/20 568 kg **217** kg 300 kg 683 kg 380 kg 178 litres 0.47 4.65 2.89 l/m^3 KFDN-100	 560 kg **214** kg 296 kg 675 kg 395kg 184 litres 0.47 4.42 2.97 l/m^3 KFDN-100	Grade 20D/20 000 kg **798** kg 320 kg 753 kg 300 kg 182 litres 0.61 6.24 2.24 l/m^3 KFDN-100	Grade 10D/20 000 kg **810** kg 315 kg 735 kg 275 kg 185 litres 0.67 6.76 2.20 l/m^3 KFDN-100
Design Concrete Slump	75mm	100mm	75mm	75mm
Measured slump during trial mix	80 – 95mm	90 – 115mm	70 – 90mm	N/A
Mean 7-day cube strength (Trial Mix)	35.8 N/mm^2	39.5 N/mm^2	23.8 N/mm^2	N/A
Mean 28-day cube strength (Trial Mix)	47.0 N/mm^2	48.6 N/mm^2	31.5 N/mm^2	N/A
Measured slump	75-95mm	100-125mm	75-80mm	70-90mm
Measured average slump	85mm	105mm	75mm	80mm
Design 28-day cube strength	49 N/mm^2	49 N/mm^2	32 N/mm^2	N/A
Designed standard deviation	7 N/mm^2	7 N/mm^2	6 N/mm^2	N/A
Works 28-day cube strength (06/03-02/04)	49.2 N/mm^2	52.6 N/mm^2	33.8 N/mm^2	23.9 N/mm^2
Standard deviation from cube test (06/03-02/04)	5.2 N/mm^2	2.6 N/mm^2	5.3 N/mm^2	5.1 N/mm^2
Difficulties encountered	1. Ready mix supplier has no spare silo for storage of 10mm recycled aggregates 2. Occasionally, the recycled aggregates contain excessive fines that cause extra water demand and faster slump loss. 3. When recycled aggregates are wetted for use, there is not too much problem in controlling the slump ex-plant. However, when the surplus wetted recycled aggregates are stored in bins for over one day, they dry out again quickly and re-spray is required to restore a saturated condition. 4. As a conclusion, handling care is of paramount importance to maintain the stability of the quality of concrete using recycled aggregates.			

Appendix B

Modulus of Elasticity of Concrete Containing 20% Recycled Aggregates

Test results to be added

Appendix C

Creep and Shrinkage of Concrete Containing 20% Recycled Aggregates

Test results to be added

Appendix I - Cost comparison between air-cooled, water-cooled and geothermal heat pump A/C systems at the Hong Kong International Wetland Park

	Cost comparison **Based on 390 TR cooling capacity**	**Air cooled A/C system HK$**	**Water cooled A/C system HK$**	**Geothermal A/C system HK$**	**Remarks**
a)	i) 3 nos. 140 TR water chillers	**3,000,000**	**1,260,000**	-	
	ii) Cooling Towers including pumps & pipework	-	**900,000**		
	iii) Chilled water circulation system including pipework	**400,000**	**400,000**	-	
	iv) Chilled water air handling units	**2,200,000**	**2,200,000**	-	
b)	i) Geothermal heat exchanger pipework	-	-	**5,600,000**	Based on 468 bore holes for Geo pipework (with 20% spare capacity)
	ii) Geothermal variable speed water circulation pumps	-	-	**450,000**	
	iii) Packaged type water source heat pumps / condensing units with DX air handling units	-	-	**4,800,000**	
	iv) Hot water circulation pumps for AHUs reheating	-	-	**270,000**	
	v) Condensing water pipework within building	-	-	**280,000**	
c)	Heat reclaim pumps including pipework	**400,000**	**400,000**	**200,000**	
d)	B.W. cost for external A/C plantrooms	**3,000,000**	**3,200,000**	-	
e)	Beautification work to cover up the unsightly air-cooled chillers / cooling towers.	**600,000**	**600,000**	-	
f)	Acoustical treatment for the air-cooled chillers / cooling towers.	**400,000**	**400,000**	-	
g)	Air ductwork	**4,600,000**	**4,600,000**	**4,600,000**	
h)	A/C electrical works	**4,000,000**	**4,000,000**	**4,000,000**	
i)	Control/CCMS	**2,700,000**	**2,700,000**	**2,500,000**	
j)	IAQ equipment	**4,200,000**	**4,200,000**	**4,200,000**	
	Grand total	**25,500,000**	**24,860,000**	**26,900,000**	
	Cost difference (compare to GHP A/C system)	**-1,400,000**	**-2,040,000**	-	
	Cost comparison in %	**95%**	**92%**	**100%**	

Appendix II - Annual Energy Usage based on 390 TR Cooling Capacity A/C Plant

Description	**Air-cooled Chillers**	**Water-cooled Chillers with Cooling Towers**	**GHP A/C System**
Estimated annual energy requirement for chiller plant	**1,133,000 kWh**	**810,000 kWh**	**823,000 kWh**
Additional energy for summer reheating for humidity control	**138,000 kWh**	**138,000 kWh**	**69,000 kWh**
Additional energy for winter heating	**200,000 kWh**	**200,000 kWh**	**32,300 kWh**
Total energy requirement	**1,471,000 kWh**	**1,148,000 kWh**	**924,300 kWh**
Extra energy requirement over GHP system	**546,700 kWh**	**223,700 kWh**	**-**
Energy comparison in %	**159%**	**124%**	**100%**
Annual saving in energy cost if GHP system is used ($)	**$492,030**	**$201,330**	**-**

Appendix III – Simple Payback Period Based On Energy Saving

Description	Air-cooled Chillers	Water-cooled Chillers With cooling tower
Extra-over initial cost for GHP system	**1,400,000**	**2,040,000**
Annual saving in energy cost if GHP system is used ($)	**$492,030**	**$201,330**
Payback period in years	**2.85**	**10.13**

Assumptions:

1. Outdoor design temperature in summer = 33^{o}C
2. Outdoor design temperature in winter = 8^{o}C
3. C.O.P for air-cooled chiller = 3
4. C.O.P. for water-cooled chiller/condensing units = 4
5. Cooling tower water temperatures: 32^{o}C –37^{o}C
6. Geothermal heat exchanger entering & leaving water temperatures in summer: 29^{o}C – 34^{o}C
7. Geothermal heat exchanger entering & leaving water temperatures in winter: 14^{o}C – 19^{o}C
8. Electricity cost $0.9/kWh

Appendix IV - Main Chiller Plant Replacement Cost Comparison over a 50 years life cycle

After	Air cooled system (HK$)	Water-cooled Chillers With cooling tower (HK$)	Geothermal A/C (HK$)
0 Years	Nil	Nil	Nil
10 years			4,800,000
12 years	5,200,000	4,360,000	
20 years			4,800,000
24 years	5,200,000	4,360,000	
30 years			4,800,000
36 years	5,200,000	4,360,000	
40 years			4,800,000
48 years*	866,666	726,667	
50 years			end of life cycle
Total replacement cost over a 50 years period (HK$) (A)	**16,466,666**	**13,806,667**	**19,200,000**
Extra Energy Cost over a 50 years period (HK$) (B)	$492,030 x 50= **24,601,500**	$201,330 x 50= **10,066,500**	-
Total cost in a 50 years period (A+B)			
Saving in initial cost over GHP system (C)	**41,068,166**	**23,873,167**	**19,200,000**
Total saving in a 50 years period if GHP is used (HK$) (A+B-C)	**1,400,000**	**2,040,000**	-
	39,668,166	**21,833,167**	-

Assumptions:

1. Air cooled chillers and AHUs need to be replaced every12 years.
2. Water cooled packaged DX units needed to be replaced every 10 years.
3. Assuming all pipework and circulation pumps etc. for both of the above system have similar life cycle therefore need not take into consideration in the above calculation.
4. Geothermal pipework life cycle of 50 years.

*Prorata of replacement cost for 2 years period