Title: **Climate Change in Hong Kong: Mitigation Through Sustainable Retrofitting**

Authors: Kevin K.W. Wan, Energy & Sustainability Consultant, Arup
Gary Cheung, Engineer, Arup
Vincent Cheng, Director, Arup

Subject: Retrofit

Keywords: Environment
Retrofit
Sustainability
Sustainability Certification

Publication Date: 2015

Original Publication: CTBUH Journal, 2015 Issue III

Paper Type:
1. Book chapter/Part chapter
2. **Journal paper**
3. Conference proceeding
4. Unpublished conference paper
5. Magazine article
6. Unpublished

Climate Change in Hong Kong: Mitigation Through Sustainable Retrofitting

Kevin Wan

Gary Cheung

Vincent Cheng

Authors

Kevin Wan, Energy & Sustainability Consultant
Arup
12777 West Jefferson Boulevard, Building D
Los Angeles, CA 90066, United States
t +1 310 578 2809
f +1 310 861 9029
e: losangeles@arup.com
www.arup.com

Gary Cheung, Engineer
Vincent Cheng, Director
Arup
Level 5 Festival Walk
80 Tat Chee Avenue, Kowloon, Hong Kong, China
t: +85 2 2528 3031
e: hongkong@arup.com
www.arup.com

Kevin Wan
Dr. Kevin K.W. Wan has 10 years of research and engineering experience in the built environment. He specializes in sustainable strategy, energy planning, net-zero energy building designs, implementation of sustainability rating systems, and mechanical engineering.

Gary Cheung
Gary H.W. Cheung has 12 years of working experience as a researcher and engineer. His expertise covers daylighting, solar energy, and low-carbon design. Cheung is also the recipient of the BREEAM Country First Award 2013 recognizing his pioneering work as the first auditor to have assessed a BREEAM-certified building in China.

Vincent Cheng
Dr. Vincent S.Y. Cheng specializes in sustainable master planning, low- and zero-carbon design, LEED & BEAM Plus certification, life-cycle analysis, and Air Ventilation Assessment (AVA). He has been involved in more than 60 LEED and BEAM Plus projects in the Hong Kong Region.

Recent reports by the Intergovernmental Panel on Climate Change (IPCC) have raised public awareness of energy use and its environmental implications. There are more than 41,000 existing tall building blocks in Hong Kong. Future projections indicate that the total number of buildings in 2050 will increase to around 58,000, at a rate of 450 buildings per year. A five-step survival strategy has been developed to aid the formulation of sustainable retrofit initiatives for the existing building stock, and to investigate long-term building energy performance under the impact of climate change. A LEED-certified existing commercial office building in Hong Kong retrofitted with these survival strategies is presented here, and the impact of climate change on future building energy use in Hong Kong is investigated.

Review of Hong Kong Electricity Use

Over the past three decades, Hong Kong has seen a significant increase in energy consumption, especially during the economic expansion of the 1980s and early 1990s. Primary energy requirements (PER) rose from 195,405 TJ in 1979 to 601,544 TJ in 2014, representing an average annual growth rate of about 3.2%.[1] Most of the PER (represented by coal, natural gas, and oil products) was used for electricity generation, which accounted for 63.3% of the total PER in 2014. The commercial sector was the largest component of consumption, accounting for 66% of the total electricity consumption in 2014. Figure 1 shows the monthly electricity consumption in the commercial sector during 1979–2012.[2]

A significant proportion of this consumption was due to the ever-growing demand for better thermal comfort, especially in terms of air conditioning during the hot, humid summer months (Lam et al. 2003 & 2004). In subtropical Hong Kong, winter is short and mild, and summer is long, hot, and humid. For commercial premises with high internal heat gains from occupants and equipment, air conditioning operates all year round (Lam 1995 & Lam et al. 2009). It was found that about 10% of the total electricity consumption was for air conditioning outside the main cooling period of March to November. Based on this assumption, monthly electricity use for air conditioning was determined, and is also shown in Figure 1. Air conditioning consumption rose from 1,120 GWh in 1979 to 8,521 GWh in 2012 (a nearly eight-fold increase) and accounted for approximately 30% of the total electricity use in the commercial sector. This is consistent with the 29–32% increase published in the Hong Kong Energy End-use Data (EMSD 2008).

Existing Buildings in Hong Kong

Buildings account for most of the region's electricity consumption (e.g., 90% in Hong Kong) and energy consumption in buildings is responsible for approximately 60% of greenhouse gas (GHG) emissions in Hong Kong (Environment Bureau 2010). Figure 2 indicates the total constructed floor area (in thousands of square meters) of residential and nonresidential buildings from 1970–2013 in Hong Kong. An increasing trend for new building construction can be observed since 1970, peaking in 1991 and followed by a downturn. In 2010, existing buildings aged 20 years or more represented 50% of the building

[1] *Hong Kong Energy Statistics Annual Report.* Census and Statistics Department, Hong Kong SAR, 1979–2008. http://www.censtatd.gov.hk.
[2] *Hong Kong Monthly Digest of Statistics.* Census and Statistics Department, Hong Kong SAR, 1979–2012. http://www.censtatd.gov.hk.

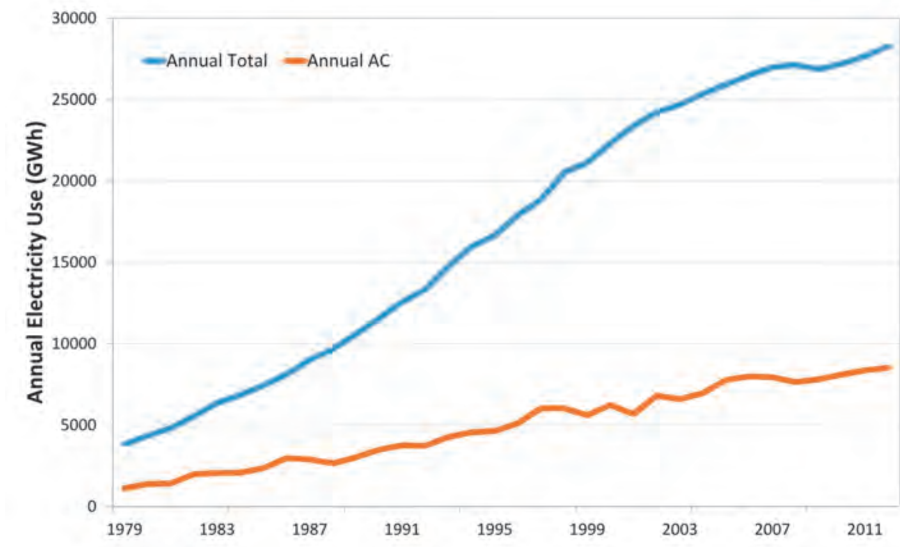

Figure 1. Monthly electricity use in the Hong Kong commercial sector (1979–2012).

stock, and 30-year-old-plus buildings represented more than 20%.

Figure 3 shows that the total building number in 2050 would be increased to around 58,000, representing a growth rate of 450 buildings per year. Existing buildings will continuously undergo replacement and refurbishment. By 2020, it is envisaged that 14% (5,600) of the existing buildings will require refurbishment or replacement, rising to 26% (10,400) in 2030 and 44% (17,600) in 2050. There is significant potential for building retrofitting as a means of preservation and avoiding greater carbon release as a result of demolition and new construction that would otherwise occur.

Carbon Emissions Reduction Targets

Buildings typically have a long life span, lasting for 50 years or more, and they account for more than a third of global greenhouse gas emissions (Guan 2009). It is therefore, important to be able to analyze how buildings will respond to climate change in the future, and assess the likely changes in energy use.

In September 2010 the Environmental Bureau in Hong Kong announced the latest plan to combat climate change, committing to reduce its carbon intensity by 50–60% by 2020 against a 2005 baseline. This translates to an absolute annual emission reduction of 28–34 million metric tons of CO_2 in 2020, or a 12–18-metric-ton reduction from business-as-usual growth (C&SD 2013). It is envisaged that existing buildings with good energy performance could help to reduce electricity use as well as carbon emissions significantly. However, designing optimal strategies that can help retrofitted buildings survive under the scenarios of climate change is the challenge. This paper formulates the survival strategies for retrofitting high-rise buildings and investigate the impact of climate change on a sustainable retrofitted building project in Hong Kong.

Sustainable Tall Building Design: Survival Strategies

Existing buildings are part of a city's heritage, and their significance in energy consumption should not be overlooked. A five-step process has been developed to aid the formulation of sustainable retrofit strategies and investigate building quality on a long-term basis under the specter of future climate change (Arup & PCA 2008, China Resources Property Limited 2014).

Step 1: Baseline establishment
For every building retrofit project, it is important to set up the baseline before determining any upgrade strategy. To establish the baseline, key performance indicators (KPI) can be obtained through conducting audits on various aspects, including energy consumption, occupant satisfaction, facilities management operation, and the condition of the building. Other baselines might include water consumption, waste generation, and Indoor Environmental Quality (IEQ). Audit results can be compared against benchmarks to determine opportunities for improvement.

Step 2: Review of the existing building designs and maintenance records
Effective property maintenance is essential to the efficient operation of buildings. Facilities Management (FM) contracts are well-executed in many instances, but lack regular reviews. As such, opportunities to maximize savings and optimize performance tend to be overlooked.

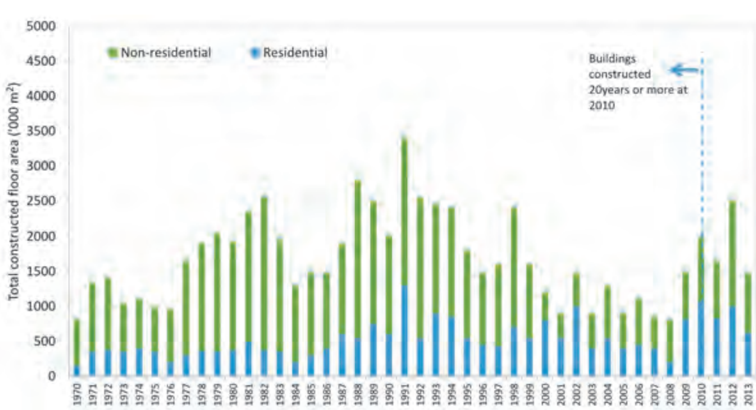

Figure 2. Constructed buildings in Hong Kong during 1970–2013.

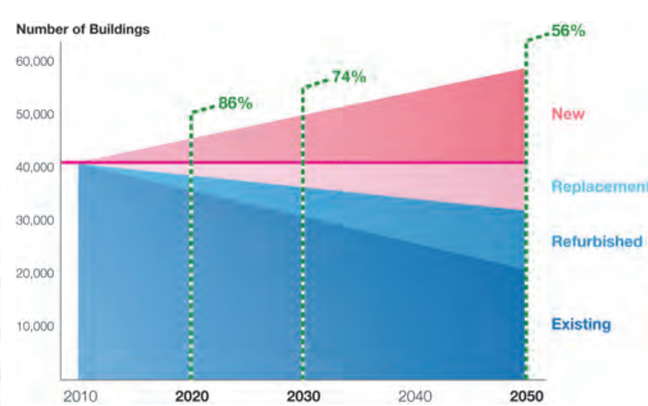

Figure 3. Projection of the variations in building mix in Hong Kong.

A modest investment in reviewing the FM strategies would probably help to evaluate and ensure the investments' effectiveness, or to set more stringent standards and provide assurance value for money.

Step 3: Establishing the targets and goals
After the completion of the audits, the measured performance can be compared against benchmarks to determine opportunities for improvement. The key targets for the building assets – such as "reduce short-term operating costs", "add value to your building stock", "obtain a marketable sustainability rating," etc., – can be identified to support the owners' business objectives.

Step 4: Determination of the retrofitting strategies
Next, optimal sustainable retrofitting strategies can then be determined to upgrade the building. Retrofitting strategies are designed to be grouped into different categories such as management, energy, emissions, IEQ, water, site, transport, etc. Each initiative is ranked according to the levels of intervention required in terms of its cost, its benefits to the environment, the occupants, and the building owner. Within each category, initiatives are listed in ascending cost order (i.e., lowest capital cost ranked first). Financial assessment tools such as simple payback calculation or internal rate of return (IRR) can help the building owners to determine the best combination of strategies that could maximize the environmental benefits with optimal costs.

Step 5: Investigation of the mitigation potentials and the climate change impact
Old buildings would typically have larger carbon emissions, considering the relative stringency of the building design requirements and technology efficiencies in the past. An investigation of how the buildings will respond to climate change would help building owners to gain a sense of the likely changes in the building energy performance and to deploy strategies in consideration of the whole building life-cycle (Day et al. 2009). Earlier work by the authors (Wan 2011, Wan et al. 2011) on the impact of climate change on building heating and cooling loads and energy use formed a useful framework for this study. A detailed investigation of the impact of climate change on building survival strategies will be covered after the case study.

Retrofitting Case Study: China Resources Building, Hong Kong

Built in 1983, the 178-meter China Resources Building (CRB) was one of the tallest buildings in Hong Kong at the time of completion. As new buildings entered the property market after the recession, the owner decided to upgrade the building to keep it competitive. Instead of the traditional "demolish and rebuild" approach, the building owner decided to take a more environmentally friendly approach (see Figure 4). After working closely with the client and the project team, the sustainability consultant finally formulated a detailed upgrade strategy based on the five-step sustainable building retrofit framework.

Energy/carbon audit
In order to have a thorough understanding of the latest building condition, the building design and operation and maintenance records were collected and reviewed. A four-year program of energy-cum-carbon audits from 2010–2013 was conducted for CRB to examine the energy consumption as well as its subsequent GHG emissions before and after the building retrofit. Based on the methodology outlined in *Guideline on Energy Audit* and *Guideline to Account for and Report on Greenhouse Gas Emissions and Removals for Building (Commercial, Residential, or Institutional Purposes)* published by the HKSAR Government, the baseline was established with the measured data.

Sustainable upgrade framework selection
After the completion of the energy/carbon audit, it was required to calculate the detailed upgrade strategies for CRB. In order to ensure the retrofit was comprehensive and sustainable, a sustainability assessment tool was utilized to distinguish CRB from other traditional retrofit projects. Given the advantages of simplicity and recognition around the globe, the LEED rating system was selected as the major upgrade framework for the CRB. The LEED system assesses building performance in five aspects, including site, water, energy, materials, and IEQ. Retrofit strategies could be designed according to the requirements described in the LEED framework. The building owner believed that the LEED standard could demonstrate its commitment to corporate social responsibility and increase the building value.

Highlights of the retrofit strategy
Reuse of building structure
The first principle implemented was the reuse of the existing structural frame. As a result, construction waste from the demolition work and the demand for new materials was greatly reduced. According to the statistics, about 97% of the area of the existing building envelope, structural core, floor, and roof were retained. The implementation of a construction-waste management plan helped to recycle or reuse 1,977 tons of generated waste (equivalent to 81.3% of the total waste). In addition, building materials with 12.7% recycled content (based on total materials value) and 51.3% regional content (within 800 kilometers of the project site) were used. Regionally manufactured building materials can reduce the carbon footprint due to fewer and shorter movements of trucks, trains, ships, and other vehicles.

Water-efficient fixtures
Water-efficient fixtures, including dual-flush water closets, low-flow urinals, and water faucets with automatic sensing devices were installed during the upgrade. These measures help to cut unnecessary water usage and waste in ways that are more effective. Compared with the LEED baseline standard, a more than 30% reduction in water consumption was achieved.

Energy systems performance

- *High-performance building façade*
  To achieve a contemporary design that also provided for long-term ease of maintenance and considered the life-cycle of the renovated building fabric, the design team chose robust construction materials such as glass panels, aluminum and stainless-steel cladding, and curtain walls. In terms of energy efficiency (see Figure 5), low-*e* (emissivity) glass panels were used as

the main façade element. The special low-*e* coating minimizes the amount of UV and infrared light entering the space, while allowing visible light through. As a result, the solar heat gain to the interior office space can be greatly reduced, while the daylight can still be used for indoor lighting.

- *Upgrade of elevator system & rezoning*
  To alleviate occupant congestion at the ground-floor elevator lobby during peak hours, the existing elevator system was replaced by one with a higher passenger-handling capacity and better energy efficiency. Moreover, the rezoning arrangement enabled the diversion of the pedestrian flows from the elevator lobbies on the ground floor alone to both the ground and second floors. Such reconfiguration of the elevator service zone not only facilitated better building management and the control of circulation flow, but also maximized the utilization of the upgraded elevator service system.

- *Efficient lighting system*
  LED light fittings were widely adopted in the building for both indoor illumination and façade lighting. T5 energy-efficient fluorescent tubes were also employed. Both lighting systems have low energy consumption, with less maintenance and long service lives compared to the conventional T8 lighting installations. The LED light fittings have rated life spans of 50,000 hours, while T5 fluorescent tubes last up to 15,000 hours (under specific test conditions). Furthermore, daylight sensors and occupancy sensors were installed in the spaces to be renovated. These types of sensors could dim down the light output (and associated power consumption) when the daylight reached the prescribed level, or when the spaces were not occupied after the pre-set time. Although the initial cost is higher, the potential energy savings and GHG emissions reductions are both benefits of the long service life.

- *Seawater cooling system*
  Seawater cooling was employed in the HVAC system, taking the advantage of its prime location close to Victoria Harbour. Seawater

Figure 4. China Resources Building, Hong Kong before (left) and after (right) retrofitting. © Marcel Lam Photography

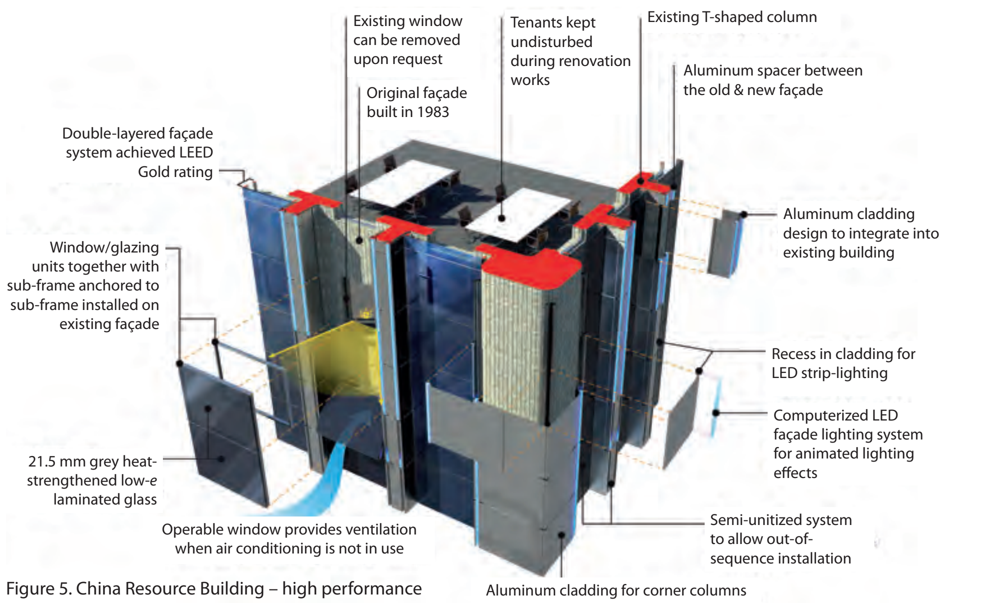

Figure 5. China Resource Building – high performance building façade. © Ronald Lu Partnership

"The Hong Kong Environmental Bureau's plan commits the region to reducing its carbon intensity by 50–60% by 2020 against a 2005 baseline. This translates to an absolute annual emission reduction of 28–34 million metric tons of CO_2 by 2020, or a 12–18-metric-ton reduction from business-as-usual growth."

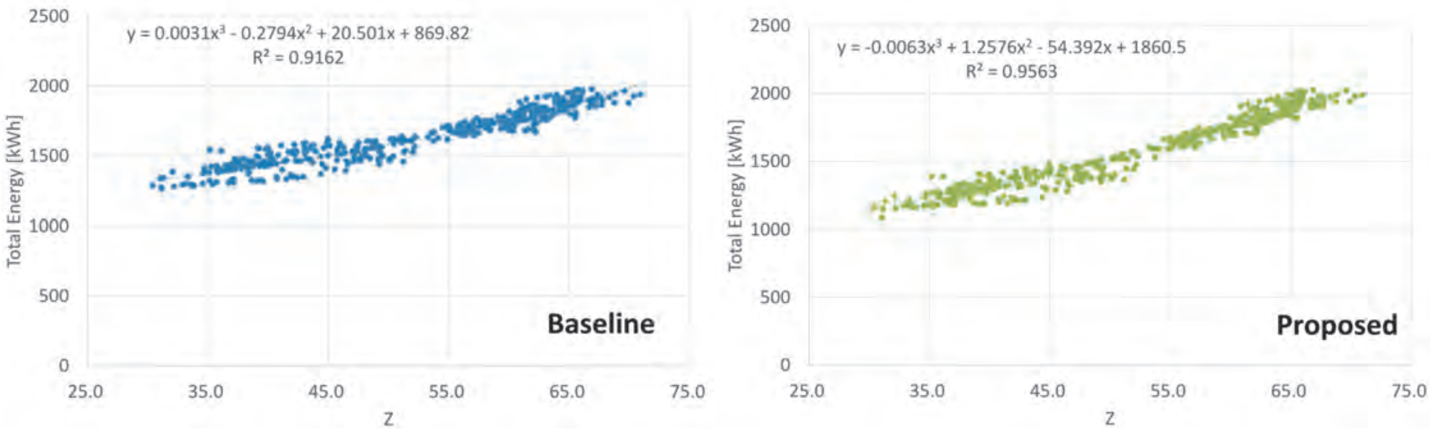

Figure 6. Correlations between the climatic index Z and the total building energy use for the baseline and the proposed cases.

provides a very stable and efficient sink for heat rejection from chillers. Compared with the common air-cooled chiller plant, the energy consumption of the seawater-cooled chiller plant is about 20% lower. In the current project, indirect seawater heat rejection was employed, and titanium tubes installed in the heat exchangers transferred heat from the condenser water to the seawater. It was noted that titanium is highly resistant to seawater corrosion and durable in this application. By using this indirect cooling method, a longer operational life could be envisaged.

The sustainable retrofit of CRB successfully achieved the LEED-CS Gold Rating in 2012. According to the energy/carbon audit, it has been shown that the electricity consumption in 2013 was reduced by 9.3%, compared to the 2008 baseline (China Resources Property Limited 2014). The improvement was due mainly to the upgrade of the building façade, reducing the solar heat gain and increasing the energy efficiency of the building plant.

Impact of Climate Change On China Resources Building

Investigation methodologies

Future building energy uses of the CRB are investigated here in the study. A methodology has been developed to investigate a baseline building's energy use under climate change and compare this to a proposed case with sustainable survival strategies. This is briefly summarized as follows:

- The researchers used principal component analysis (PCA), a multivariate statistical technique for the analysis of the dependencies existing among a set of inter-correlated variables. Because of its ability to categorize the complex and highly inter-correlated set of meteorological variables as one or more cohesive indices, PCA tends to give a better understanding of the cause/effect relationship and thus give a good indication of the electricity use in fully air-conditioned office buildings (Lam et al. 2009 & Lam et al. 2010). PCA was conducted for both historical Hong Kong weather data (1979–2014) and future predicted data (2015–2100). A new climatic variable Z was determined as a function of the three meteorological parameters: dry-bulb temperature (DBT, in °C), wet-bulb temperature (WBT, in °C), and global solar radiation (GSR, in MJ/m^2).

- Multi-year hourly building energy simulations were conducted for both the baseline (LEED/ASHRAE 90.1) and the proposed cases (with sustainable retrofits) for the CRB models, using the eQuest simulation tool for the period 1979–2014. Hourly building energy consumption was also determined.

- Regression models were developed to correlate the total building energy use with the corresponding climatic variable Z based on the 36-year simulated results. The coefficient of determination (R^2) varied from 0.91 to 0.95 in the baseline and the proposed cases. The R^2 for both cases was greater than 0.9, indicating strong correlation between energy use and the corresponding Z (see Figure 6).

- Future trends of building energy use were estimated using the regression models and the climatic variable Z for the 21st century.

Future energy use and survival strategies

The future energy use of CRB for both baseline (ASHRAE 90.1) and the proposed retrofit were investigated based on the future climatic index Z and the developed regression models in order to estimate the likely changes in energy consumption and to investigate the mitigation potentials of the implemented retrofit strategies. Figure 7 shows the predicted annual building energy use for the baseline and the proposed cases during 2015–2100. A distinct increasing trend can be observed for both cases. The gap between the baseline and the proposed case scatter plots suggested the potential energy savings from the CRB retrofit. The increasing rate of the total building energy use of the baseline and the proposed cases are 10.9 MWh and 15.5 MWh per year, respectively. This indicated that, though the retrofit strategies could successfully achieve the energy savings in the current climate, their effectiveness would be reduced if real future climate change outstrips the baseline rate.

Annual average total building energy use between 1979–2100 was analyzed and a summary is shown in Figure 8. There would clearly be a gradual increase of building energy use from one period to another in both the baseline and the proposed case. The building energy consumption in the proposed case would overtake the baseline level (1979–2014)

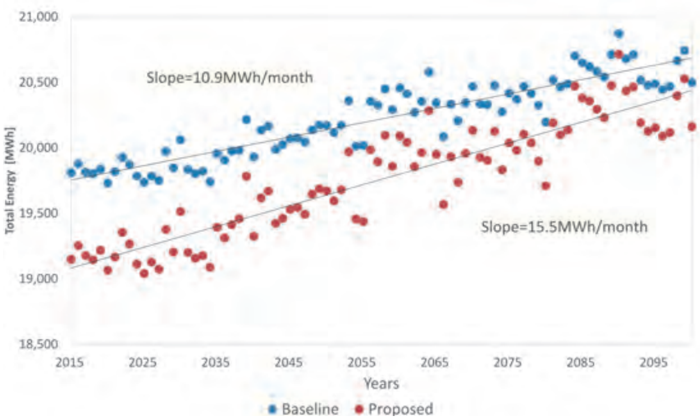

Figure 7. Long-term trends of annual total energy use for the baseline and proposed cases from 2015 to 2100.

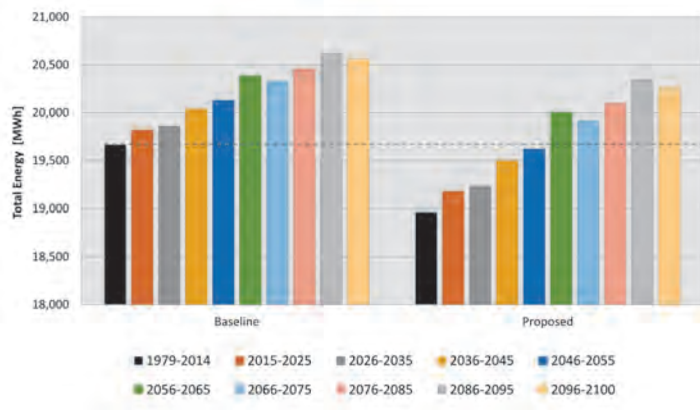

Figure 8. Comparison of annual average building energy use between the past years (1979–2014) and future years (2015–2100) of the baseline and the proposed cases (with sustainable retrofitted strategies).

in the period 2056–2065. This indicated that the retrofit strategies could help to prolong and mitigate the impact of climate change on the CRB project for approximately 40 years.

Conclusions

In Hong Kong, the urban population and constructed building area continues to grow, indicating that there will be a growing demand for energy use. The increase in climate-change-associated summer discomfort may result in increased cooling demands. More electricity use for air conditioning would lead to larger emissions, which in turn would exacerbate climate change and global warming. This would put more pressure on the already over-stretched electrical power supply systems.

In the selected project, the implemented sustainable retrofit strategies successfully mitigated the impact of the climate change on building energy use for almost 40 years. Although the work was conducted in the context of the subtropical climate of Hong Kong, the approach could be applied to new-build and existing building projects in different climates. Investigation of future building energy use and carbon emissions would help building owners and designers to select appropriate sustainable building designs and retrofit strategies to cope with the changing climate in the 21st century. ■

Unless otherwise noted, all photography credits in this paper are to Arup.

Acknowledgement

The authors would like to express their sincere gratitude to China Resources Properties Limited for providing the images for the case study. Measured weather data was obtained from the Hong Kong Observatory of the Hong Kong SAR. We acknowledge the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the WCRP's Working Group on Coupled Modeling (WGCM) for their roles in making available the WCRP CMIP3 multi-model data set. Support of this data set is provided by the Office of Science, US Department of Energy. Special thanks are expressed to Kaj E. Pippo for his assistance on the data analysis.

References

ARUP & PROPERTY COUNCIL OF AUSTRALIA (PCA). 2008. ***Existing Buildings: Survival Strategies: A Toolbox for Re-energising Tired Assets.*** Melbourne: PCA.

CENSUS & STATISTICS DEPARTMENT (C&SD), HONG KONG SAR. 2013. ***Hong Kong Annual Digest of Statistics.*** Hong Kong: C&SD.

CHINA RESOURCES PROPERTY LIMITED. 2014. ***Energy-cum-carbon Audit for China Resources Building.*** 4th Audit Report. REP/209896, September 2014.

DAY, A. R.; JONES, P. G.; MAIDMENT, G. G. 2009. "Forecasting Future Cooling Demand in London." ***Energy and Buildings.*** Vol. 41(9): 942–48.

ELECTRICAL & MECHANICAL SERVICES DEPARTMENT (EMSD), HONG KONG SAR. 2008. ***Hong Kong Energy End-use Data.*** Hong Kong: EMSD. http://www.emsd.gov.hk.

ENVIRONMENT BUREAU. 2010. ***Hong Kong's Climate Change Strategy and Action Agenda: Consultative Document.*** Hong Kong: Environment Bureau.

GUAN, L. 2009. "Implication of Global Warming on Air-conditioned Office Buildings in Australia." ***Build Research and Information.*** Vol. 37(1): 43–54.

LAM, J. C.1995. "Building Envelope Loads and Commercial Sector Electricity Use in Hong Kong." ***Energy***. Vol. 20(3): 189–94.

LAM, J. C.; CHAN R. Y. C.; TSANG C. L. & LI, D. H. W. 2004. "Electricity Use Characteristics of Purpose-built Office Buildings in Subtropical Climates." ***Energy Conversion Management.*** Vol. 45(6): 829–44.

LAM, J. C. & LI, D. H. W. 2003. "Electricity Consumption Characteristics in Shopping Malls in Subtropical Climates." ***Energy Conversion Management.*** Vol. 44(9): 1391–1398.

LAM J. C., WAN K. K. W. & CHEUNG K. L. 2009. "An Analysis of Climatic Influences on Chiller Plant Electricity Consumption." ***Applied Energy.*** Vol. 86(6): 933–40.

LAM, T. N. T.; WAN, K. K. W.; WONG, S. L. & LAM, J. C. 2010. Impact of climate change on commercial sector air conditioning energy consumption subtropical Hong Kong. ***Applied Energy.*** Vol. 87(7): 2321–327.

WAN, K. W. 2011. ***An Investigation of the Impact of Climate Change on Energy Use in Buildings in Different Climate Zones Across China.*** PhD Dissertation, City University of Hong Kong.

WAN, K. K. W.; LI, D. H. W.; LIU, D. & LAM, J. C. 2011. "Future Trends of Building Heating and Cooling Loads and Energy Consumption in Different Climates." ***Building and Environment.*** Vol. 46(1): 223–34.