CONSTRUCTION
INDUSTRY COUNCIL
建造業議會

RETROFITTING EXISTING BUILDING (ENERGY EFFICIENCY) -A QUANTITATIVE APPROACH

RESEARCH SUMMARY

Construction Industry Council

Retrofitting existing building (energy efficiency) -a quantitative approach

Research Summary

Author

Dr Tin Tai CHOW
City University of Hong Kong

Published by

Construction Industry Council,
Hong Kong SAR

DISCLAIMER

The information given in this report is correct and complete to the best of knowledge of the authors and publisher. All recommendations are made without guarantee on the part of the authors or publisher. The authors and publisher disclaim any liability in connection with the use of the information given in this report.

Enquiries

Enquiries on this research may be made to the CIC Secretariat at:

CIC Headquarters
38/F, COS Centre, 56 Tsun Yip Street, Kwun Tong, Kowloon

Tel.: (852) 2100 9000

Fax: (852) 2100 9090

Email: enquiry@cic.hk

Website: www.cic.hk

FOREWORD

There are numerous energy retrofitting technologies available in market. Their performance and initial investment are different. Clients must decide what kinds of products should be chosen in their retrofitting work. Although equipment suppliers could provide some relevant information, the claimed energy saving may be based on laboratory test. The issue has not been investigated comprehensively. The Construction Industry Council (CIC) well recognized the industry need and worked together with the City University of Hong Kong to initialize the project, aiming at providing practical recommendations to the industry.

The research team led by Dr Chow has done a remarkable work. They first established an evaluation framework for the performance of the energy retrofit technologies based on the technical and economic aspects. Then they identified twelve technologies for detailed study after consulting a steering committee covering air-conditioning, lighting, lift and others. Although huge difficulties were encountered during the course of case study and data collection, the research team successfully collected the data of total 31 cases.

After thorough assessment, four technologies are considered most promising. Various factors affecting the performance of the energy saving technologies have also been discussed. These findings and discussion will be helpful for building owners/facility management. I would like to congratulate and thank the research team and all those who have contributed to it.

Ir Albert CHENG
Executive Director
Construction Industry Council

PREFACE

I am very pleased to know that the CIC Research Fund supports this research project on the survey study of the performances of energy retrofit works implemented in existing buildings in Hong Kong. This topic is indeed very closely related to the current practices in the building industry for the fulfillment of the statutory requirements on energy efficiency in building systems. To achieve the goal set by the Hong Kong Government in 2025 on energy saving, the promotion of more extensive use of the energy saving technologies in buildings is crucial. With the completion of this research project, more detailed and useful information can be provided to the building industry, particularly the building owners/facility management in the consideration of any energy retrofit work to be executed.

To successfully conduct this research project, the acquisition of sufficient real case information is necessary and important. Thanks to the help of various professionals from the building industry, the research team has managed to complete substantial amount of case assessments. Through the course of the study, they helped establish the connections with responsible parties in the industry for smooth proceeding of the assessment works. In fact, this research project also offers an opportunity to strengthen the link between the University and the building industry.

The research outcomes highlight the various factors that affect the performances of respective energy retrofit technologies. The assessment results provide baselines to the building stakeholders to estimate the feasibilities (in particular economically) of the energy retrofit works, thus enhancing their intention and confidence in the decision making. In view of climate change mitigation and sustainable development of the city, it is believed that energy retrofitting is an effective way for continual economic and population growth in Hong Kong.

C.M. TAM
Head of Division of Building Science and Technology
City University of Hong Kong

RESEARCH HIGHLIGHTS

The awareness of climate change and the scarcity of natural resources brought about international protocols on the reduced reliance on fossil fuels. In Hong Kong, the building sector consumes over 90% of the territory-wide electricity generation, of which 66% are consumed in the commercial sector (EMSD, 2013). In 2015, the Hong Kong Government announced the strategic Energy Saving Plan for the city (EB, 2015), in that the energy intensity (i.e. the ratio of energy demand to GDP) was to be reduced by 40% by 2025 using 2005 as the base year. To realize this goal, substantial improvement on building energy efficiency over the current situation is crucial, particularly through energy retrofitting in existing buildings. Although the principles are known to the industry, the actual performances of the energy saving technologies in real installations are limited and usually from building owners or equipment suppliers with little discussions on the encountered technical problems. The claimed energy savings may even be based on rough estimation or ideal expectations. In this regard, it is the intent of this study to carry out a more detailed assessment of the performances of various energy retrofit technologies implemented in Hong Kong.

Retrofit technology and case identification

To facilitate the identification of feasible energy retrofit technologies and potential cases for assessment, a steering committee was established which consisted of 10 team members. The project co-ordination and cases line-up were implemented through the committee meetings followed by the networking of individuals through their day-to-day working partners, professional institution activities, technical conferences, research seminars, as well as publication search. During the project period, totally seven committee meetings had been organised.

Potential retrofitting technologies applicable to this subtropical modern city were identified in view of their energy saving potential and practicality, in particular considering our high-rise and high-density urban environment with more attentions placed on air-conditioning and lighting systems. At first, over 20 items of retrofitting technology had been identified. These were gradually confined to 12 items for reporting. For existing buildings, the applications were restricted by the available plant room space and high conversion costs. For some technologies, difficulties were found in quantifying the actual savings coming from specific technology because of the randomness in human behaviour, and therefore difficult to evaluate the cost benefits. In reality, the building owner would not single out individual energy saving measures for implementation one by one. Instead, they would work out what could be the most effective in system conversion and achieving the best saving. This sometimes made the assessment of individual energy retrofit technology impossible.

The same retrofitting technology when adopted in different buildings may have different levels of performance satisfaction and cost saving. It was therefore desirable to include in the investigation at least three studying cases per each retrofitting. Adequate details were to be reported in terms of plant design specification and operation data, before and after the changes,as well as the technical difficulties encountered during the plant conversion processes. The case selection was dependent on the system availability during the project period, and the opportunity of acquiring quality performance data set. Through this, the practitioners can have better judgement about the likely situation when the technology is to be implemented in their own premises.

Knowledge dissemination

During the project period, part of the research output was presented in the 7th Greater Pearl River Delta (GPRD) Conference on Building Operation and Maintenance in 2016 (Chow *et al.* 2016) which highlighted various aspects which the facility management should be aware of when deciding if an energy retrofit work was to be implemented. The project works were also highlighted in the "Hong Kong Report on the State of Sustainable Built Environment 2017" published during the World Sustainable Built Environment 2017 Hong Kong (WSBE17, 2017) jointly organised by the CIC and the Hong Kong Green Building Council in June 2017.

Difficulty encountered

The case assessment work was originally scheduled for completion within the first year of the study. However, the plan was later on proved to be too optimistic. On many occasions, the properties management teams were found reluctant to participate. In some cases, no full record data was found available before and after the retrofitting work to allow for accurate assessment. In other cases, there were significant changes in occupancy and activities, making the direct comparison irrelevant. Sometimes the record data was left behind by those who have already left the company and so further clarifications could not be made. Consequently, at the later stage, building types other than office were also considered and that in some of the assessed cases, the energy saving issues were implemented during the construction of the buildings rather than retrofitting. Indeed, not all the technologies could have three assessed cases.

Overview of assessment results

The evaluation of the performance of the energy retrofit technologies was generally based on two aspects, namely the technical and economic issues. For the technical side, it was mainly the energy saving potential in terms of the percentage energy saving (*PES*). Regarding the economic merit, a simple payback period (*SPP*) was employed. Here, the year-round running cost saving also took into account any maintenance cost/saving incurred by the implementation of the energy retrofit work as well as any other running cost besides the energy cost. In the calculation of the energy cost saving, no escalation of the unit energy cost was considered.

Through the case assessment processes, it was found that both the *PES* and *SPP* varied widely among different technologies and even different cases of the same technology. Besides, the trends of the *PES* and *SPP* could be substantially different. This could be attributed to the different information involved in the two parameters. *PES* only reflected the energy saving percentage but not the amount of energy reduced which *SPP* was more correlated to. Another important factor which affected the *SPP* was the initial cost of the retrofit work. This could fluctuate substantially from case to case and from time to time. The marketing strategies of the suppliers and the contractors could influence the initial cost to a great extent.

Nevertheless, based on the assessment results, four energy saving technologies were considered most promising, namely the use variable-speed primary chiller pump station, the addition of CO_2 sensor to reduce fresh air rate, the replacement of light tubes by T5 or LED fixtures and the addition of heat pump to domestic hot water supply.

Various factors were found to affect the performances of the energy saving technologies in different aspects and to different extents which the building owners/facility management should pay more attention to in the planning of respective energy retrofit work. They were namely the security of system operation, scale of retrofit work, consolidation of work, extent and ease of work, impact on maintenance load, selection of supplier/contractors for the retrofit work, interference from users and appropriateness of system settings.

From the assessed cases, a good technical performance in terms of a percentage energy saving did not necessarily yield an attractive economic benefit as expressed by a simple payback period. Conversely, in some cases, the payback periods were still acceptable despite the fact that the percentage energy savings achieved were small. Hence, in order not to be misled by the percentage energy saving, a prudent prediction of the cost benefit should be done. This included an estimation of the pre-retrofit energy consumption data (preferably year-round). With this information, the corresponding payback period at different percentage energy saving could be determined which could help the building owners/facility management justify if the planned energy retrofit work was cost-effective.

Recommendations

To further promote the implementation of energy saving technologies, the Government can consider offer more incentive schemes to the building owners, to help improve the economic merits of the energy saving technologies. Meanwhile, tighter statutory requirements on building systems energy efficiencies/consumptions can be enforced which can shift the building owners’ focus from the economic performances to the technical performances of the energy saving technologies. Public awareness is also important as human behavior is often a very significant factor which affects the success of respective energy saving technologies.

CONTENTS

1 INTRODUCTION

1.1 Background

The awareness of climate change and scarcity of natural resources brought about international protocols on the reduced reliance on fossil fuels. In Hong Kong, the building sector consumes over 90% of the territory-wide electricity generation, of which 66% are consumed in the commercial sector (EMSD, 2013). Offices, retail shops and restaurants are identified as the key energy consumers within the commercial sector. In office segment in particular, space air-conditioning and electrical lighting installations respectively account for 50% and 27% of the total energy use. Hong Kong's population is projected to reach 8.3 million by 2030. Without any proactive measures, the electricity consumption in buildings by then will reach 57,605 GWh, under the so called business-as-usual (BAU) scenario.

In view of the community needs, the Hong Kong Green Building Council (HKGBC) has proposed a holistic approach based on the demand-side management conception. The HK3030 campaign (HKGBC, 2012) was officially launched in year 2013, targeting at a reduction of building energy consumption by 30% in Hong Kong by the year 2030, using the 2005 consumption level as the baseline. This initiative is fully supported by the Hong Kong Government. If this turns out to be achievable, the actual electricity savings by then will be over 33,000 GWh, equivalent to around 60% reduction when compared with the BAU scenario (HKGBC, 2012). In 2015, the Hong Kong Government announced the strategic Energy Saving Plan for the city (EB, 2015), in that the energy intensity (i.e. the ratio of energy demand to GDP) was to be reduced by 40% by 2025, also using 2005 as the base year.

To realise this goal, substantial improvement on building energy efficiency over the current situation is crucial. HKGBC estimates that within this 60% reduction, 38% could be met through technology advancement and uptake in the commercial sector, followed by the similar 10% cut in the residential sector, and the remaining 12% is achievable through user behavioral change. Furthermore, within the 38% quota of the commercial sector, those existing commercial buildings are expected to contribute 26% after major retrofitting in the centralised building services installations (CBSI). Since the life spans of typical CBSI are 5-30 years, therefore 70-80% of these systems should have been retrofitted by 2030. It is based on this philosophy that the HK3030 target was worked out.

In Hong Kong, because of the public education and government policy, carrying out energy audits has been common in commercial buildings. As a result, various energy saving measures were implemented. Many of them are claimed to be highly successful by the building owners or the equipment suppliers. Nevertheless, very few actual performance data are made known to the public, and the encountered technical problems are not fully disclosed. While properties developers and facilities management teams are confronted by the social responsibility and statutory regulations, window dressing efforts are often taken place to deal with the uncertainties in financial burden and engineering risk. In view of this, HKGBC has plans to introduce a series of practical guidelines to help the building professionals to move along this direction. However, in many cases the energy saving potential presented are rough estimations or ideal expectations, or bound to be qualitative in nature. With these limitations, the overall support or strength acting onto the building industry at present may not be adequate to realise the HK3030 target.

In order to promote the wider application of energy efficiency measures in the coming 15 years, the building industry of Hong Kong is in need of reliable field measured data and convincing technical information to demonstrate the engineering practicality, energy saving potential, as well as cost benefits. Such an evaluation of merits is best done by the third independent party rather than by the equipment supplier or the building owner. A stage-by-stage research study along this direction is therefore carried out. Working on the office buildings can be the starting points of the comprehensive study, and this can be followed by investigations of other building types in turn, like retail, restaurant and residence.

1.2 Aims and Objectives

In alliance with the industrial collaborators, this project started with studying the energy efficiency measures applicable to the existing office buildings in Hong Kong. This was the project stage one. Through an expert research team led by the academics (that have no direct conflict of interest with the commercial market), the goal was to furnish the local building industry with reliable engineering data for the implementation of useful energy saving measures in major retrofit work of the existing building stock of Hong Kong.

With a focus at the office buildings, the specific objectives were:

(i) To identify the existing office buildings in which the retrofitting energy saving technologies can be made available for field measurements;

(ii) To carry out quality in-situ studies on the selected energy systems and to evaluate the effectiveness and the implementation difficulties;

(iii) To quantify and generalise the long-term system performance and cost benefits; and

(iv) To disseminate the research findings to the public, in particular the building industry of Hong Kong.

The experiences gained in this stage of work were then beneficial to the future extension of the study to other building types.

1.3 Scope

To achieve the research objectives, the scope of work of this project covered the following 4 phases.

Phase 1 – Identification of feasible energy retrofit technologies and potential cases for assessment;

Phase 2 – Collection of case information including site survey and in-situ measurement where necessary;

Phase 3 – Performance analysis of energy retrofit works; and

Phase 4 – Dissemination of the research findings to the public.

2 RESEARCH METHODOLOGY

2.1 Establishment of a Steering Committee

To facilitate the identification of feasible energy retrofit technologies and potential cases for assessment, a steering committee was established which consisted of 10 team members. In the group there were three academics from the City University of Hong Kong and the other seven practicing professionals from professional bodies, leading property management and engineering consultant firms. All members were carrying decades of solid working experiences in their own field. The project co-ordination and cases line-up were implemented through the committee meetings followed by the networking of individuals through their day-to-day working partners, professional institution activities, technical conferences, research seminars, as well as publication search. During the project period, totally seven committee meetings had been organized.

2.2 Selection of Feasible Retrofit Technologies

Potential retrofitting technologies applicable to this subtropical modern city were identified in view of their energy saving potential and practicality, in particular considering our high-rise and high-density urban environment. As the major energy consumption items for office buildings were the air-conditioning and lighting installations, more attentions had been placed to these systems. Generally speaking, the expertise and vision of the team members were found most useful in screening the retrofitting technologies for the existing built environment, rather than based on advanced literature search and equipment supplier recommendations.

At first, over 20 items of retrofitting technology had been identified. These were gradually confined to 12 items as listed in Table 1 with category numbers assigned for easier references in subsequent sections. Many practical technologies were found suitable for the Hong Kong built environment. However, their applications were mostly limited to new buildings due the available plant room space and high conversion costs for existing buildings. For other examples, difficulties were found in quantifying the actual savings coming from specific technology because of the randomness in human behaviour, and therefore difficult to evaluate the cost benefits.

Table 1 Final potential retrofitting technologies identified

System	Retrofitting Technology	Cat
Air-conditioning	• Replace air-cooled chiller with water-cooled type	AC1
	• Upgrade to oil-free/magnetic bearing chiller	AC2
	• Use variable-speed primary chiller pump station	AC3
	• Use fan coil unit with variable-speed-drive fan	AC4
	• Add CO_2 sensor to reduce fresh air rate	AC5
	• Adopt ductwork pressure optimisation	AC6
Lighting	• Replace light tubes by T5 or LED fixtures	E1
	• Adopt lighting with motion/occupancy sensor controls	E2
	• Add daylight sensor with/without dimming effect	E3
Lift	• Use lift motor with variable-voltage-variable-frequency drives and/or regenerative power	LE1
Other technologies	• Add heat pump to domestic hot water supply	O1
	• Install solar collectors: thermal or photovoltaic	O2

2.3 Case Identification and Assessment

The same retrofitting technology when adopted in different buildings may have different levels of performance satisfaction and cost saving. Moreover, there are two power companies currently in services in Hong Kong with different tariff schemes. It was therefore desirable to include in the investigation at least three studying cases per each retrofitting technology which should include, as far as possible, different combinations of building age, geometry, height, facade construction and materials, as well as different business trades or ownership, and in different locations of the city. The case selection would depend on the system availability during the project period, and the opportunity of acquiring quality performance data set. Priority was to be given to those systems available for measurements before and after the retrofits. The development of mutual trust between the properties management team and the research team became important in order to generate a case study report with high quality. The attitude of the research team remained to include only in the report those studied cases worked out to be reliable. Here the expertise of the steering committee members in association with the analytical skill of the front-line researchers was found important in decision making. Table 2 summarizes the numbers of cases assessed for each type of energy retrofit technologies considered. Totally there were 31 cases investigated.

Table 2 Summarised numbers of cases assessed

Cat	No. of cases	Cat	No. of cases
AC1	3	E1	3
AC2	2	E2	3
AC3	3	E3	2
AC4	3	LE1	2
AC5	3	O1	2
AC6	2	O2	3

2.4 Case Reporting

The evaluation of the performance of the energy retrofit technologies was generally based on two aspects, namely the technical and economic issues. For the technical side, it was mainly the energy saving potential in terms of the percentage energy saving (*PES*)

$$PES = 100x\left(1- \frac{\text{Post - retrofit energy consumption}}{\text{Pre - retrofit energy consumption}}\right) \qquad (1)$$

In the determination of the pre- and post-retrofit energy consumption, year-round values were adopted. In the cases where only data within a shorter period of time was available, it would be projected for one year.

Regarding the economic merit, a simple payback period (*SPP*) was employed as calculated from

$$SPP = \frac{\text{Extra initial cost}}{\text{Year-round running cost saving}} \qquad (2)$$

Here, the year-round running cost saving also took into account any maintenance cost/saving incurred by the implementation of the energy retrofit work as well as any other running cost besides the energy cost. In the calculation of the energy cost saving, no escalation of the unit energy cost was considered.

For each assessed case, an assessment report would be made which recorded the details of the retrofit work. Each report generally included six main sections which provided information about the building type, the details of the system configuration before and after the retrofit work, the energy and economic merit analyses and the discussion on the factors that might affect the performance of the retrofit work. The last two parts were particularly important as it could help the readers identify the causes of the performance derivations of each type of retrofit work when applied to different buildings. A sample of the report is shown below.

Brief description of the retrofit work

1. Building description (building type, age, location, number of stories, etc.)
2. System description (before and after the retrofit complete with illustrating diagrams where applicable)
3. Energy performance analysis (methodology, field measurements, mathematical analysis)
4. Cost analysis (evaluating assumptions, cost-benefit analysis)
5. Technology evaluation (technical difficulties encountered, appropriateness of the retrofitting scale, design optimisation etc.)
6. Overall remarks

2.5 Knowledge Dissemination

During the project period, part of the research output was presented in the 7th Greater Pearl River Delta (GPRD) Conference on Building Operation and Maintenance in 2016 (Chow *et al.* 2016) which highlighted various aspects that the facility management should be aware of when deciding if an energy retrofit work was to be implemented. The project findings were also highlighted in the “Hong Kong Report on the State of Sustainable Built Environment 2017” published during the World Sustainable Built Environment 2017 Hong Kong (WSBE17, 2017) jointly organized by the Construction Industry Council and the Hong Kong Green Building Council in June 2017.

3 RESEARCH FINDINGS AND DISCUSSION

3.1 Difficulties Encountered

The case assessment work was originally scheduled for completion within the first year of the study. However, the plan was later on proved to be too optimistic. On many occasions, the properties management teams were found reluctant to participate. In some cases, no full record data was found available before and after the retrofitting work to allow for accurate assessment. In other cases, there were significant changes in occupancy and activities, making the direct comparison irrelevant. Sometimes, in situ measurements were impossible for acquiring operation data before the retrofit. Sometimes the record data was left behind by those who had already left the company and so further clarifications could not be made. Consequently, at the later stage, building types other than office were also considered and that in some of the assessed cases, the energy saving issues were implemented during the construction of the buildings rather than retrofitting.

In the assessment process, the comparison of the pre- and post-retrofit system performance should preferably be based on the same operating conditions such as weather, occupancy, building zone usage, etc. However, this was generally very difficult to achieve. As mentioned previously, the year-round system performance might be projected from data within a short of time. This might induce some degrees of uncertainty in the assessed results, particularly for some retrofit technologies with merits which were expected to vary widely throughout the year. In some cases, the pre-retrofit system did not have the necessary devices to measure the system performance precisely. Consequently, some assumptions were adopted to predict the pre-retrofit system performance.

3.2 Overview of Performances for the Cases Investigated

Through the case assessment processes, it was found that both the *PES* and *SPP* varied widely among different technologies and even different cases of the same technology. Besides, the trends of the *PES* and *SPP* could be substantially different. This could be attributed to the different information involved in the two parameters. *PES* only reflected the energy saving percentage but not the amount of energy reduced which *SPP* was more correlated to. Another important factor which affected the *SPP* was the initial cost of the retrofit work. This could fluctuate substantially from case to case and from time to time. The marketing strategies of the suppliers and the contractors could influence the initial cost to a great extent. Of course, there were other factors which had been mentioned previously.

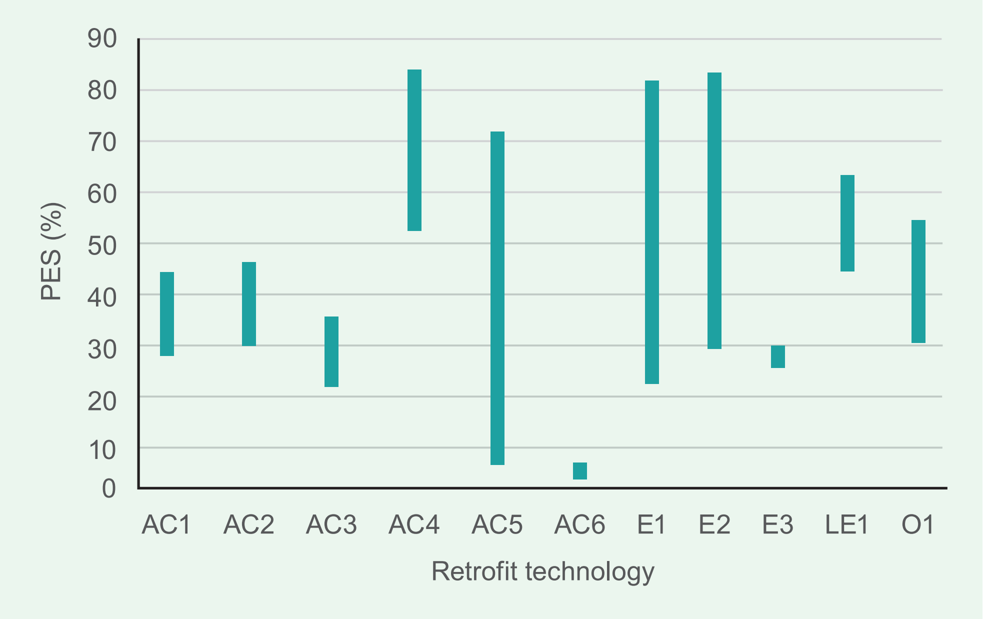

Figure 1 Summarized *PES* for the various energy retrofit technologies investigated

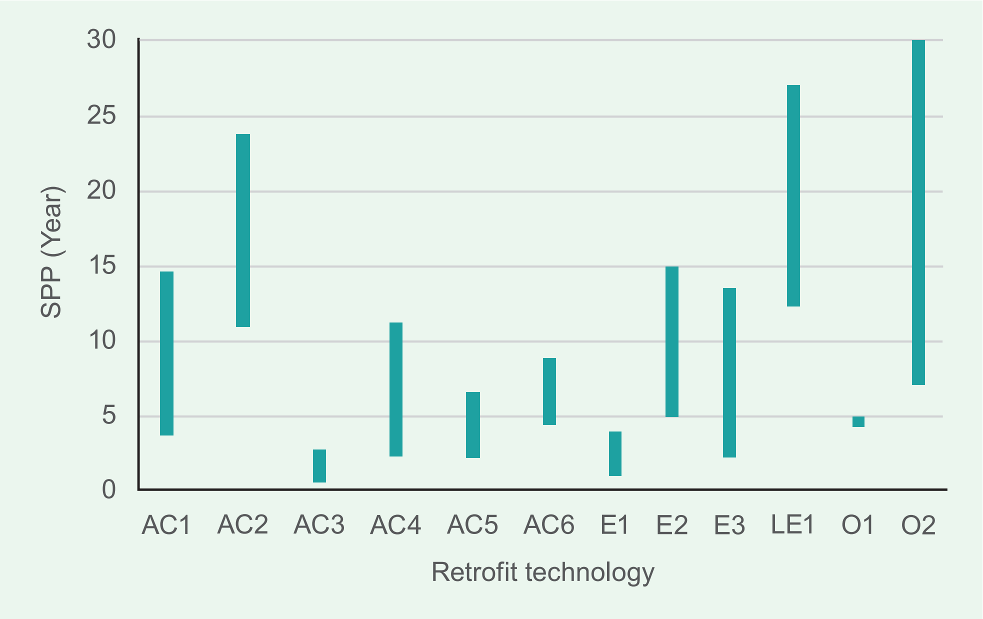

Figure 2 Summarized *SPP* for the various energy retrofit technologies investigated

Figures 1 and 2 summarize the variations of the *PES* and *SPP* for all the energy retrofit technologies investigated. *PES* was not calculated for the installation of solar collectors (O2) due to the different nature of the technology and that its maximum *SPP* actually went beyond 30 years. More detailed discussions on the findings for the respective energy retrofit technologies were given in the next section.

3.3 Factors Affecting the Performances of Respective Energy Retrofit Technologies

In the following sub-sections, the assessment results from the various cases of each energy retrofit technology were summarised and compared in order to highlight those factors that led to the performance variations. It was expected that this helped the readers estimate the appropriate situations if those energy retrofit technologies were to be applied to their buildings.

Replace air-cooled chiller with water-cooled type

For this technology, totally three cases were assessed with details summarised in Table 3. In Cases AC1-1&2, the retrofit works were implemented in high-rise office buildings while in Case AC1-3 a multi-storey institutional building complex was involved. In Case AC1-2, a new air-cooled chiller was installed to provide air-conditioning during the non-office hours in weekdays, Saturday and holidays. It was also considered as a backup unit in the case when there was shortage of water supply to the cooling tower. This inevitably increased the initial cost as only new water-cooled chillers were purchased in the other two cases. The operation time of this air-cooled chiller was not deemed to be short. Indeed, the energy consumption from this air-cooled chiller accounted for over one third of the total energy consumption from all the chillers. This explained why the *PES* was the lowest in Case AC1-2.

Regarding the Case AC1-1, three sets of the existing air-cooled chillers were retained as backup units but they seldom operated. In the Case AC1-3, only new water-cooled chillers were purchased and installed in one zone of the building complex, and air-cooled chillers from the other zones of the building complex provided the backup to the chiller plant. As the chiller plants at different zones were inter-connected, the new water-cooled chiller plant was also used in priority to supply chilled water to other zones of the building complex. In this regard, the operating time for the new water-cooled chiller plant was substantially longer than those in the Cases AC1-1&2, particularly during the winter time. This explained why the water consumption was significantly higher in the Case AC1-3. The extra maintenance cost of the Case AC1-3 was also much higher, as the facility management conducted water sampling and testing each month rather than every three months as stated in the statutory requirement. Nevertheless, the resulting *SPP* in the Case AC1-3 was still considered attractive despite the unfavorable low electricity cost.

Table 3 Summarized assessment results for the replacement of air-cooled chiller with water cooled type

	Case AC1-1	Case AC1-2	Case AC1-3
Building type	Office	Office	Institutional
Plant capacity (TR)	1,650	1,100	1,500
Year-round energy saving (kWh)	3,322,560	812,939	3,020,500
PES (%)	45.24	28.34	36.95
Electricity cost (HKD/kWh)	1.37	1.36	0.99
Extra annual water cost (HKD)	67,089	97,131	278,168
Extra annual maintenance cost (HKD)	80,000	187,920	260,000
Initial cost (HKD)	14,200,000	12,000,000	15,180,000
SPP (Year)	3.2	14.6	6.2

The extra initial cost adopted in the assessment was the total supply and installation cost for the new chiller plant rather than the difference between a water-cooled and an air-cooled plant. The reason was that the pre-retrofit energy performance data usually came from an old and de-rated system. Meanwhile, the post-retrofit energy performance data was based on a new system. Hence, the estimated *PES* was higher than that if both the pre- and post-retrofit data were from new air-cooled and water-cooled plants. In this regard, the cost of a new air-cooled plant was not deducted in the present study in order to avoid an under-estimation of the *SPP*.

Upgrade to oil-free/magnetic bearing chiller

For this retrofit technology, two cases were assessed with the key information given in Table 4. Case AC2-1 involved a low-rise office building while in Case AC2-2 the retrofit work was applied to a high-rise multi-purpose building. In Case AC2-1, only a new air-cooled chiller was installed to replace an old air-cooled one. However, in Case AC2-2, the original water-spray-assisted air-cooled plant was completely demolished and replaced by a new water-cooled system. As the energy performance of a water-spray-assisted air-cooled chiller was still worse than that of a water-cooled chiller, the calculated *PES* was not solely due to the adoption of oil-free chillers. Besides the chillers, new water pumps (both condenser and chilled water) and new cooling towers as well as new power supply and control system were also installed in the Case AC2-2. This led to a higher initial cost as compared to the situation when only the chillers were replaced. The new condenser water system also resulted in a much higher maintenance cost. Still, the *SPP* for the Case AC2-1 was not better than that for the Case AC2-2. The main reason was that the capacity of the new chiller in the Case AC2-1 was not fully utilized. According to the builder owner, the peak operating part-load ratio for the new chiller was only around 70% during the peak load season when it was solely used to provide air-conditioning to the entire building. In other words, a chiller with a smaller capacity and consequently a lower initial cost could be used which helped improve the *SPP*. Clearly for this energy retrofit technology, the equipment cost was critical for a favorable *SPP*. With the growing acceptance and advance of the technology, it could be expected that the price of oil-free chillers would drop in future which in turn helped improve the economic merit.

Table 4 Summarized assessment results for the upgrade to oil-free/magnetic bearing chiller

	Case AC2-1	Case AC2-2
Building type	Office	Multi-purpose
Plant capacity (TR)	150	1,350
Year-round energy saving (kWh)	64,858	1,042,729
PES (%)	29.91	47.71
Electricity cost (HKD/kWh)	1.232	1.36
Extra annual water cost (HKD)	N/A	22,668
Extra annual maintenance cost (HKD)	20,000	200,000
Initial cost (HKD)	1,447,859	12,800,000
SPP (Year)	24.2	10.7

Use variable-speed primary chiller pump station

For this retrofit technology, three cases were assessed with details summarized in Table 5. In Case AC3-1, the chiller plant was used to serve a multi-story commercial building which operated with a daily schedule including Saturday and holidays. In Case AC3-2, the chiller plant provided air-conditioning to a high-rise building complex which mainly operated during the office hours. Case AC3-3 involved a new hotel building which required air-conditioning at 24 hours per day. In this circumstance, Case AC3-3 would offer a higher *PES* as there was probably a longer period during the day when the system operated at part-load. Conversely, the *PES* in Case AC3-2 should be lower as the system mostly operated within the time when the air-conditioning demand was the highest within the day. The situation in Case AC3-1 was a little bit controversial as there were still constant-speed chilled water pumps (three out of totally seven pumps) operated in the system which tended to exaggerate the *PES* achieved. In case they were all converted to variable-speed pumps, the resulting *PES* would likely be reduced to below 30%.

Table 5 Summarized assessment results for the use of variable-speed primary chiller pump station

	Case AC3-1	Case AC3-2	Case AC3-3
Building type	Commercial	Multi-purpose	Hotel
Pump motor power (kW)	30 x 2 75 x 2	37 x 5 11 x 4	18.5 x 3
Year-round energy saving (kWh)	172,460	42,139	55,472
PES (%)	34.32	21.60	36.37
Electricity cost (HKD/kWh)	1.08	1.36	1.47
Initial cost (HKD)	411,510	150,000	50,000
SPP (Year)	2.2	2.6	0.6

The required installation works for the three cases were different. In Case AC3-1, the frequency inverters were added to existing water pumps. Hence, modifications of existing power and control wirings had to be done which contributed substantial installation cost. On the other hand, in Case AC3-2, frequency inverters were installed during the time when the chilled water pumps and the related power and control system were replaced. Hence, the extra electrical wirings specific to the retrofit work was minimal. This was also the situation in Case AC3-3 as the whole air-conditioning system was erected during the construction of the building. Nevertheless, all the three cases indicated that this retrofit technology was proven both in terms of technical and economic merits.

Use fan coil unit with variable-speed-drive fan

For this retrofit technology, three cases were assessed as shown in Table 6. In Case AC4-1, new fan coil units (FCU) equipped with variable-speed-drive (VSD) fan were added to the toilets of a multi-story retail building. In Case AC4-2, new fan motors with the accompanying new control units were installed to existing fan coil units in a guest room and lift lobby of a hotel building. In Case AC4-3, new variable-speed-drive fan coil units were installed in a new hotel building with two units at the lift lobbies of two typical guest room floors selected for assessment. In Cases AC4-1&3, the initial cost only took into account the equipment cost, and installation cost was assumed to be included in the installation of the fan coil units. Meanwhile in Case AC4-2, an extra installation cost had to be considered. It was evident that the inclusion of installation cost increased the *SPP* significantly. In other words, it would not be economically beneficial to only upgrade the fan drive and the control. The adoption of this retrofit technology should only be considered if new fan coil units were to be installed.

Table 6 Summarized assessment results for the use of fan coil unit with variable-speed-drive fan

	Case AC4-1	Case AC4-2	Case AC4-3
Building type	Retail	Hotel	Hotel
Fan coil capacity (cfm)	800	800 x 2	800 x 2
Year-round energy saving (kWh)	547	733	1449
PES (%)	77.15	51.99	84.39
Electricity cost (HKD/kWh)	1.08	1.05	1.47
Initial cost (HKD)	2,201	8,580	4,580
SPP (Year)	3.7	11.1	2.2

Add CO_2 sensor to reduce fresh air rate

For this retrofit technology, three cases were assessed with the key information indicated in Table 7. For all the three cases, CO_2 controls were added to existing primary air units (PAU's). In both Cases AC5-1&2, each related PAU was used to supply fresh air to a number of floors (21 floors each for Case AC5-1 and 15 floors for Case AC5-2) through the flow control dampers on respective floors. CO_2 sensors were installed to modulate the flow dampers which eventually affected the supply flow rates of the PAU's. A frequency inverter, already fitted to each PAU, would then change the fan speed based on a constant-supply-fan-pressure control. Unlike Case AC5-1, only one floor was equipped with CO_2 control in Case AC5-2 as a trial run. This explained why the *PES* was significantly lower than those of the other two cases as only the energy consumptions of the PAU's before and after the retrofit work were measured. The small scale of application also led to a higher *SPP* in Case AC5-2. In Case AC5-3, an individual PAU unit was used to supply fresh air to each floor. Hence, new CO_2 sensors were installed at selected positions of each floor, and the control signal was used to modulate the fan speeds of the PAU's through newly installed frequency inverters. In this regard, the initial cost per floor was substantially higher than that in Case AC5-1, although the value was the highest in Case AC5-2 due to its small scale of application.

Table 7 Summarized assessment results for the addition of CO_2 sensor to reduce fresh air rate

	Case AC5-1	Case AC5-2	Case AC5-3
Building type	Office	Commercial	Multi-purpose
Primary air unit motor power (kW)	45 x 2	18.5	4 x 15
Year-round energy saving (kWh)	43,485	3,236	81,640
PES (%)	25.62	6.22	71.81
Electricity cost (HKD/kWh)	1.37	1.08	1.36
Initial cost (HKD)	200,000	2,200	225,000
SPP (Year)	3.4	6.6	2.0

The pre- and post-retrofit energy data in Cases AC5-1&2 were recorded within a short period of time. Hence, there were some degrees of uncertainties when they were used to project the year-round data. Meanwhile, full year-round data was provided by the building owner in Case AC5-3. Hence, the calculated *PES* was more solid although it appeared to be quite high. For this retrofit work, the energy saving potential did not merely come from the fan power of the PAU's, but also the reduction of cooling load of the PAU's. However, the assessment of the cooling load saving was very difficult in actual situations as there were usually no flow meter installed at the PAU's. Hence, there was no way to determine the cooling capacities of the PAU's. Consequently, that part of energy saving was not considered in the assessment. Generally speaking, by ignoring the unusually low *PES* in Case AC5-2, this retrofit technology could also be regarded as promising. Of course, a reasonable difference in CO_2 level between the outdoor and the indoor setting was the prerequisite.

Adopt ductwork pressure optimization

For this technology, two cases were assessed, both being applied to high-rise office buildings with the key results shown in Table 8. The main difference between the two cases was that in Case AC6-1, the work was applied to all typical floors (totally 33) of an existing building and that full year-round pre- and post-retrofit energy consumption data were available. In Case AC6-2, a new building was involved. Hence, there was no system performance data without ductwork pressure optimization. To make the assessment, only one of the typical floors (6/F) was selected for measurement. The energy consumption of the air-handling unit (AHU) with ductwork pressure optimization was recorded for two weeks. Then ductwork pressure optimization was disabled and the respective bi-weekly energy consumption was measured. After that, the system was resumed back to the situation with ductwork pressure optimization. The annual performance of the technology was projected based on the bi-weekly data. This inevitably created certain degrees of uncertainty, particularly in view of the fact that the benefit of this technology should vary throughout the year. However, this was the only way to make the assessment in this circumstance. To worsen the situation, the logged average ambient temperature during the measurement period without ductwork pressure optimization was lower than that with ductwork pressure optimization. In this sense, the calculated PES was likely to be under-estimated. The results indicated in Table 8 for Case AC6-2 only refers to one floor.

Table 8 Summarized assessment results for the adoption of ductwork pressure optimization

	Case AC6-1	Case AC6-2
Building type	Office	Office
Air handling unit motor power (kW)	11 x 33	18.5
Year-round energy saving (kWh)	29,005	664
PES (%)	5.5	1.9
Electricity cost (HKD/kWh)	1.42	1.05
Initial cost (HKD)	170,000	6,000
SPP (Year)	4.1	8.6

From Table 8, it appeared that the *PES* of this technology was not high. Of course, it varied with several conditions like the respective settings for the control algorithm. In fact, the effective functioning of the control algorithm relied on various factors such as the normal operation of the variable-air-volume (VAV) boxes and the proper selection of the temperature set points. The latter was somehow not easy to control as it depended on the users' preferences. Meanwhile, a good maintenance practice was essential to ensure optimal energy performance of this technology. For an existing building, the implementation of this technology was usually handled only by the existing control supplier/contractor. In this regard, the initial cost might not be reasonable. To improve the situation in order to have a better *SPP*, the building owner/facility management should get more information from the control supplier particularly the predicted *SPP* before making the decision. As this retrofit work involved mainly the control equipment, the initial did not vary with the capacity of the air handling unit. Hence, it could be expected that the economic merit of this retrofit technology be better when it was applied to a higher capacity system.

Replace light tubes by T5 or LED fixtures

For this retrofit technology, three cases were assessed as summarized in Table 9. Case E1-1 involved the common area of one floor of a low-rise office building, Case E1-2 involved the lift lobby floor of a multi-story commercial building and Case E1-3 involved the common area of all the typical floors (totally 22) of an industrial building.

Table 9 Summarized assessment results for the replacement of light tubes by T5 or LED fixtures

	Case E1-1	Case E1-2	Case E1-3
Building type	Office	Commercial	Industrial
Light fitting type before retrofit	T8	Halogen lamp	T8
Light fitting type after retrofit	LED	LED	T5
Total rated wattage of new light fittings (W)	34 x 49	11 x 395	14 x 88 28 x 440
Year-round energy saving (kWh)	9,828	109,420	25,568
PES (%)	56.94	82.61	22.22
Electricity cost (HKD/kWh)	1.232	1.035	1.2
Initial cost (HKD)	43,120	91,324	85,184
SPP (Year)	3.6	0.8	2.8

For this retrofit technology, the types of original and new light fittings affected the resulting *PES* significantly. This explained why the *PES* was the highest in Case E1-2, as the halogen lamp was comparatively more energy-intensive and that the LED lighting was considered more energy-efficient. In fact, in Case E1-2, only the light bulbs were replaced and the existing lighting fixtures were retained. Hence, the installation cost was relatively lower which led to a much small *SPP* as compared to the other two cases, although the electricity cost was the lowest in Case E1-2. Meanwhile, the energy merit of replacing T8 by T5 fitting in Case E1-3 was the lowest, but the lower cost of T5 fitting resulted in a smaller *SPP* as compared to that of Case E1-1. Nevertheless, it should be reminded that the *SPP* depended on the operating schedule of the light fittings. A longer daily operating period for the light fittings would yield a shorter *SPP*. However, the lifetime of the light fittings was usually in terms of the total operating hours. In other words, a longer daily operating period would mean that the overall operating years of the light fittings became shorter. Hence, the *SPP* should not simply be compared in the absolute sense but the time gap between the *SPP* and the expected operating years should also be aware of.

In Cases E1-2 and E1-3, the pre- and post-retrofit energy consumptions were calculated from the rated energy demands of the light fittings and the respective operating times. However, the situation was different in Case E1-1 as a daily dimming schedule was also adopted for the light fittings. Hence, the energy consumptions at different dimming modes were measured at site. It was found that the power factor of the LED fittings departed substantially from the rated value when they were dimmed. Consequently, it would not be appropriate to just measure the running current for determining the energy demand of dimmed LED fittings. A watt meter should be used instead.

Adopt lighting with motion/ occupancy sensor controls

For this retrofit technology, three cases were assessed with key data shown in Table 10. The applied areas and the respective operating schedules of the light fittings were different in the three cases. In Case E2-1, the retrofit work was implemented at the 1/F toilets of a low-rise office building with the light fittings operated from Monday to Saturday. In Case E2-2, the light fittings above the parking spaces of a high-rise commercial complex were involved which operated daily within a specific period. In Case E2-3, selected lightings which operated at 24 hours per day at the staircase of a multi-story office building were fitted with this retrofit technology.

Table 10 Summarized assessment results for the adoption of lighting with motion/occupancy sensor controls

	Case E2-1	**Case E2-2**	**Case E2-3**
Building type	Office	Commercial	Office
Existing light fitting type	LED	T5	T5
Total rated wattage of light fittings (W)	34 x 5	28 x 110	12 x 8
Year-round energy saving (kWh)	185.9	9,542	828
PES (%)	29.40	38.09	84.40
Electricity cost (HKD/kWh)	1.232	0.988	1.137
Initial cost (HKD)	3,456	44,550	6,400
SPP (Year)	15.1	4.7	6.8

The energy merit of this retrofit technology depended on the occupancy schedule of the applied area which was difficult to predict and compare among different types of building zones. Besides, the setting of the control algorithm was also a critical issue. In Case E2-1, the controlled light fittings were switched off when the occupancy sensors detected "no occupancy" for half an hour. The reason for selecting such a long waiting period was that the controlled light fittings were all located at the cabinet areas of the toilets. Hence, a longer waiting period had to be used in order to prevent disturbance to the users at the cabinet areas. This inevitably reduced the activating time of the occupancy control and resulted in a smaller *PES*. In both Cases E2-2&3, the waiting periods of the occupancy control were much shorter (within minutes). Unlike Case E2-1, the controlled light fittings were only dimmed (down to different extents between Cases E2-2&3 with Case E2-3 being lower) instead of switched off. The much higher *PES* found in Case E2-3 also reflected that in normal situation, the staircase was rarely used by the occupants.

In both Cases E2-2&3, the occupancy controllers were integrated in the light fittings while in Case E2-1, the occupancy controllers were external to the light fittings. Consequently, the installation cost in Case E2-1 was much higher which led to a longer *SPP*. Despite a higher *PES* found in Case E2-3, the respective *SPP* was worse than that in Case E2-2 due to several reasons. The first one was that in Case E2-3, the light fittings needed to be relocated from the ceiling level to the side wall. This resulted in a much higher initial cost per light fitting as compared to that in Case E2-2. The smaller scale of work was also another cause. From Table 10, the year-round energy saving per light fitting in Case E2-3 exceeded that in Case E2-2 only by less than 20% despite a nearly 116% higher *PES* found in Case E2-3 as compared to that in Case E2-2. This was due to the much lower rating of the light fittings in Case E2-3. As the initial cost of the occupancy controller did not vary much with the rating of the light fitting under the same situation, it was evident that a higher rating for the light fitting was beneficial for achieving an attractive *SPP*.

Add daylight sensor with/without dimming effect

For this retrofit technology, two cases were assessed as summarized in Table 11. In Case E3-1, the technology was applied to part of the non-essential light fittings at 1/F corridor of a low-rise office building which operated under a daily schedule during weekdays. In Case E3-2, the involved light fittings were located at the exterior zones of a high-rise office building at G/F and 2/F. Unlike those in Case E3-1, the light fittings operated daily within specific period throughout the whole year, and that some of them were essential light fittings.

Table 11 Summarized assessment results for the addition of daylight sensor with/without dimming effect

	Case E3-1	Case E3-2
Building type	Office	Office
Existing light fitting type	LED	LED
Total rated wattage of light fittings (W)	34 x 10	32 x 30 20 x 9 18.5 x 10 27 x 3
Year-round energy saving (kWh)	208	2,876
PES (%)	30.28	25.61
Electricity cost (HKD/kWh)	1.232	1.4
Initial cost (HKD)	3,466	9,200
SPP (Year)	13.5	2.3

The control strategies of the daylighting control were slightly different in the two cases. In Case E3-1, once the light sensor detected sufficient light level at designated position, the involved light fittings dimmed progressively. In Case E3-2, all related light fittings were switched off when the light sensor was triggered. In both cases, the year-round energy performances of the retrofit technology were projected from logged data which covered only a short period of time. Unlike the occupancy level, the daylight level varied substantially throughout the year. Hence, there was a higher degree of uncertainty in the predicted *PES* and *SPP* under the present approach. Similar to the occupancy control, a larger total wattage of light fittings led to a shorter *SPP*. Besides, the longer operating hours of the light fittings in Case E3-2 also helped reduce the *SPP*. Of course, the higher electricity cost exercised in Case E3-2 was beneficial to lowering the *SPP*.

Use lift motor with variable-voltage-variable-frequency drives and/or regenerative power

For this retrofit technology, two cases were assessed as results summarized in Table 12. In Case LE1-1, the retrofit technology was applied to two service lifts of a hotel building, while in Case LE1-2, all the passenger lifts in the residential blocks of a residential estate were involved. The benefit of this retrofit technology depended substantially on the utilization of the lifts which in turn was affected by the nature of the building. For a residential building as in Case LE1-2, the peak usage period was usually in the morning when the occupants went out for work or school during weekdays. For the other time of the day, the utilization was generally low. Meanwhile, in Case LE1-1 with a hotel building, there were routine work like cleaning of guest rooms which necessitated the use of the service lifts over a longer period of time within a day. Although the lift utilization might not affect the resulting *PES* much, it definitely impacted the SPP substantially as indicated in Table 12.

Table 12 Summarized assessment results for the use of lift motor with variable-voltage-variable-frequency drives and/or regenerative power

	Case LE1-1	Case LE1-2
Building type	Hotel	Residential
Number of lifts	2	41
Year-round energy saving (kWh)	55,704	377,165
PES (%)	63.72	45.19
Electricity cost (HKD/kWh)	1.05	1.3
Initial cost (HKD)	705,000	13,500,000
SPP (Year)	12.1	27.5

For this retrofit technology, the existing lift supplier was basically the sole provider of the retrofit work (similar to the situation for ductwork pressure optimization). This generally led to a high initial cost. Indeed, the *SPP* for both assessed cases were over 10 years. Again, more information should be collected for bargaining with the lift supplier before making the final decision. A claimed *PES* was clearly insufficient as it did not truly reflect the actual amount of energy saved which was important in the determination of the economic merit. Usually, this retrofit technology was referred as lift modernization by the lift suppliers. They stated that the retrofit work did not simply involve the replacement of the drive but also other work to be done in the lift shaft for fitting the new drive system. They also claimed that there were other benefits for lift modernization besides energy saving like a shorter travel time, a quieter and more reliable operation, etc. if these side benefits could be expressed in terms of cost savings, then the resulting *SPP* could be improved.

Add heat pump to domestic hot water supply

For this retrofit technology, two cases were assessed with the key information shown in Table 13. Case O1-1 involved a multi-story community building in which new heat pumps as well as a solar water heating system were installed to replace the existing electric heaters for providing warm water to a swimming pool. In Case O1-2, a new high-rise hotel building was facilitated with heat pumps and solar thermal collectors to provide hot water to the guest rooms. Due to the design of the piping system, the heat pumps did not function in the optimal way. A modification of the pipework was conducted to help improve the utilization of the heat pumps and hence the energy performance of the whole system. The data indicated for Case O1-2 in Table 13 referred to this modification.

Table 13 Summarized assessment results for the addition of heat pump to domestic hot water supply system

	Case O1-1	Case O1-2
Building type	Community	Hotel
Capacity of heat pumps (kW)	120 + 32	114 x 4
Year-round energy saving (kWh)	143,340	62,869
PES (%)	54.98	30.50
Electricity cost (HKD/kWh)	1.23	1.47
Extra annual maintenance cost (HKD)	7,600	N/A
Initial cost (HKD)	856,900	400,000
SPP (Year)	5.1	4.3

In Case O1-1, the solar water heating system contributed part of the energy saving achieved. That meant that the energy reduction attributed to the heat pump systems were smaller. However, as there were insufficient devices in the plant which allowed individual calculation of the heating duties made by the solar water heating system and the heat pumps, the lumped data had to be adopted. Indeed, the initial cost also included the solar water heating system whose capacity was small as compared to the heat pumps. Hence, the present results were still considered appropriate. Full year-round pre- and post-retrofit energy consumption data was provided by the building owners. Hence, the predicted *PES* and *SPP* were quite solid.

In Case O2-2, as the whole plant was erected during the construction of the building, there was no pre-retrofit energy data available. In view of this, only the benefit of the modification work was considered. Nevertheless, the energy saving potential of hot water heat pumps was proven and that the choice of suppliers was sufficient. It could be expected that the SPP of the technology was acceptable.

Install solar collectors: thermal or photovoltaic

Due to the nature of this technology, the implementation as a retrofit work encountered various problems particularly in the fulfillment of the respective statutory requirements for installing the solar panels on the roof of the building. Consequently, for all the three assessed cases, the technology was applied to new buildings as shown in Table 14. Case O2-1 involved a multi-story institutional building and that a small-capacity solar photovoltaic (PV) system was installed as a demonstration project. In Case O2-2, PV panels were fitted to the roof of a low-rise institutional building. Case O2-3 involved a high-rise hotel building in which a solar thermal system was built to pre-heat the makeup water of the hot water supply system. The solar panels (evacuated tubes) covered nearly the entire roof area.

Table 14 Summarized assessment results for the installation of solar collectors: thermal or photovoltaic

	Case O2-1	Case O2-2	Case O2-3
Building type	Institutional	Institutional	Hotel
Solar panel type	Photovoltaic	Photovoltaic	Thermal
Total rated capacity of solar panel (kW)	4	152	52.7*
Year-round energy generated (kWh)	3,388	102,356	57,448
Electricity cost (HKD/kWh)	1.0	1.232	1.47
Initial cost (HKD)	590,000	15,000,000	632,000
SPP (Year)	174.1	119.0	7.5

*Based on a temperature difference of 30 °C between collector and ambient.

From Table 14, the calculated *SPP* for the two solar PV systems were very long, particularly in Case O2-1. This could be explained by the small scale of work. The specific cost (cost per unit rated capacity) was nearly 50% higher than that in Case O2-2. Another reason was the low electricity cost exercised in Case O2-1. If both values were taken as those found in Case O2-2, the corresponding *SPP* in Case O2-1 would be less than 96 years. Still, it was very long. The specific outputs of the solar PV systems in Cases O2-1&2 were 847 and 675 kWh/year/kW respectively. The lower value found in Case O2-2 was due to the fact that the PV panels were not facing the optimal direction. Besides, the shading effect from adjacent tall buildings was substantial. These values were substantially lower than the normal value of 1,333 kWh/year/kW (Peng and Lu, 2013). Of course, the normal value did not take into account any loss in the power conditioning system. If this normal value was simply adopted, the respective *SPP* in Cases O2-1&2 would drop to 61 and 60.3 years respectively.

For the solar thermal system in Case O2-3, the specific cost was much lower than the two PV systems in Cases O2-1&2. Combined with a specific output of nearly 1,000 kWh/year/kW and a higher electricity cost, the resulting *SPP* in Case O2-3 appeared to be more attractive, particularly for use in buildings with a large hot water demand like hotels and hospitals. Of course, one concern of using the solar thermal heating system was the possible risk of damage of the solar panels by objects from adjacent higher buildings.

3.4 Conclusive Remarks

Based on the assessment results, four energy saving technologies were considered most promising, namely the use variable-speed primary chiller pump station, the addition of CO_2 sensor to reduce fresh air rate, the replacement of light tubes by T5 or LED fixtures and the addition of heat pump to domestic hot water supply.

Various factors were found to affect the performances of the energy saving technologies in different aspects and to different extents, which the building owners/facility management should pay more attention to in the planning of respective energy retrofit work. They were namely the security of system operation, scale of retrofit work, consolidation of work, extent and ease of work, impact on maintenance load, selection of supplier/contractors for the retrofit work, interference from users and appropriateness of system settings.

From the assessed cases, a high *PES* did not necessarily yield an attractive *SPP*. Conversely, in some cases, the *SPP*'s were still acceptable despite the fact that the *PES's* achieved were small. Hence, in order not to be misled by the *PES*, a prudent prediction of the cost benefit should be done. This included an estimation of the pre-retrofit energy consumption data (preferably year-round). With this information, the corresponding *SPP* at different *PES* could be determined, which could help building owners/facility management determine if the planned energy retrofit work is cost-effective.

4 RECOMMENDATIONS

Whereas the Government has launched the Buildings Energy Efficiency Ordinance in 2012 (EMSD, 2012), it is still not sufficient to safeguard the achievement of the target set by the Government in 2025. The attitude of the Government becomes very critical. To further promote the implementation of energy saving technologies, there are generally two ways which the Government can consider. The first one is to offer more incentive schemes to the building owners. This helps improve the economic merits of the energy saving technologies. The other way is to tighten the statutory requirements on building systems energy efficiencies/consumptions. This can shift the building owners' focus from the economic performances to the technical performances of the energy saving technologies. Of course, public awareness is also important as human behavior is often a very significant factor affecting the success of respective energy saving technologies.

5 REFERENCES

Chow, T.T., C.K. Lee, Alan M.L. Fong, C. F. Leung, Alan Hung, Martin Wan, Wommy Wong, Colin Chung, Paul Sat and Isaac Tsang (2016), Retrofitting existing buildings: a quantitative approach to energy project evaluation, *Proceedings of the 7th Greater Pearl River Delta (GPRD) Conference on Building Operation and Maintenance – "SMART Facilities Operation and Maintenance", Hong Kong, 2016,* 4-13.

Peng, J and L. Lu (2013), Investigation on the development potential of rooftop PV system in Hong Kong and its environmental benefits, *Renewable and Sustainable Energy Reviews,* 27:149-162.

EB (2015), *Energy Saving Plan for Hong Kong's Built Environment 2015~2025+*, Environment Bureau, the Hong Kong Special Administrative Region.

EMSD (2013), *Hong Kong Energy End-use Data 2013*, Electrical and Mechanical Services Department, the Hong Kong Special Administrative Region.

EMSD (2012), Buildings Energy Efficiency Ordinance (Cap 610), Electrical and Mechanical Services Department, the Hong Kong Special Administrative Region. Webpage: http://www.beeo.emsd.gov.hk/en/mibec_beeo.html

HKGBC (2012), HK3030: a vision for a low carbon sustainable built environment in Hong Kong by 2030, Hong Kong Green Building Council. Webpage: www.hkgbc.org.hk/HK3030

WSBE17 (2017), World Sustainable Built Environment Conference 2017. Webpage: http://www.wsbe17hongkong.hk/

CIC Task Force on Research

Mr. Jimmy TSE
Prof. Christopher LEUNG
Ir Joseph MAK
Prof. James PONG
Prof. Sze-chun WONG
Ir Chi-chiu CHAN
Mr. Shu-jie PAN

Research Team

Principal Investigator

Dr. T. T. CHOW

Co-Investigators

Dr. Yongjun SUN
Dr. C. K. LEE

Collaborators

Ir. Conrad Wong, Yau Lee Holdings Limited
Ir. Colin Chung, Parsons Brinckerhoff Asia
Ir. Ronald Chin, Hong Kong Green Building Council

Student Helpers

Mr. K. K. CHAN
Mr. P. H. NG
Ms. Y. Y. CHAN

建造業議會
Construction Industry Council

Address 地址 38/F, COS Centre, 56 Tsun Yip Street, Kwun Tong, Kowloon
九龍觀塘駿業街56號中海日升中心38樓

Tel 電話 : (852) 2100 9000

Fax 傳真 : (852) 2100 9090

Email 電郵 : enquiry@cic.hk

Website 網址 : www.cic.hk

cic_hk
HKCIC
Construction Industry Council
CICHK
HKCIC
Construction Industry Council Hong Kong

2018

CIC Research Report No. CICRS_022