BUSINESS ENVIRONMENT COUNCIL
商界環保協會

A Guide to Energy Efficient Retrofits of Office and Hotel Buildings

FULL GUIDE

Foreword

Energy is an essential part of daily life but enhancing the energy efficiency of Hong Kong's buildings is important for a number of reasons. It helps reduce carbon emissions and as a result tackle climate change, one of the most urgent and harmful global challenges of our time. It also reduces air pollution, important for the liveability of Hong Kong. Eliminating unnecessary energy usage in our buildings also avoids wasting resources and makes good business sense.

We are pleased that the Government has stated the importance of energy saving not only in its Climate Action Plan 2025 but also in its Energy Saving Plan 2015. Government has set targets for 2025, of reducing the energy intensity of the economy by 40%, and has committed to taking a lead in doing so.

The business community also has an important role to play in enhancing the energy efficiency of our buildings. There are many mature technologies that can be used to reduce the energy usage of our building stock, and often these can be introduced with net savings. These are win–win solutions and the earlier that we start to use them, the sooner Hong Kong reduces its overall carbon emissions to the atmosphere.

I am pleased that BEC is launching this Retrofit Guide and Calculator, which are practical enabling tools to support businesses in their transition to well-managed energy efficient buildings. Our approach recognizes that businesses need information to make good decisions as to energy saving solutions that offer the biggest reductions for the expenditure involved. We hope these tools will offer business at least some of the information they need in their pathway to highly energy efficient buildings.

Mr. Richard Lancaster
Chairman
Business Environment Council Limited

As the Chairman of BEC's Energy Advisory Group, which has steered this project along the way, I am pleased to promote this *Guide to Energy Efficient Retrofits of Office and Hotel Buildings* to all those looking for cost-effective energy saving solutions.

The Hong Kong Government published the Energy Saving Plan for Hong Kong's Built Environment 2015~2025+ in 2015, aiming to reduce the energy intensity of Hong Kong's economy by 40% by 2025. More recently in 2017, it published Hong Kong's Climate Action Plan 2030+ with targets to reduce carbon intensity by 65-70% by 2030. The Action Plan highlights energy efficiency of buildings as the most important step after improving the fuel mix.

But what are the most cost-effective energy saving solutions? How does a building manager or a sustainability manager build the business case for capital spend? That's the purpose of this Guide. It aims to arm sustainability officers and building managers with the information needed to act and invest – at least part of the "proof of performance" that they look for.

The Guide focuses on energy efficient technologies and initiatives for commercial buildings, which are responsible for 60% of Hong Kong's building electricity consumption. The Building Energy Code already provides a framework for new buildings, hence our focus on existing buildings.

It shows the cost savings, energy savings and return on investment for important and mature energy saving technologies and initiatives in simple "marginal abatement cost curves", calculated using robust simulations. The Retrofit Calculator that accompanies the Guide is a simple, easy-to-use excel spreadsheet that enables calculation of approximate energy and cost savings for specific buildings.

The Retrofit Calculator and Guide are backed up by case studies produced with the help and support of BEC members. Without our members, we would not have been able to produce this report, and we thank them for their help in doing so.

Mr. Tony Small
Chairman
Energy Advisory Group
Business Environment Council Limited

For Konrad-Adenauer-Stiftung, energy efficiency is vital in reducing the risk of severe climate change. We are firmly committed to the goal of keeping the global temperature rise under the 2°C maximum set out in the Paris Agreement. We recognise the important contribution of all cities and countries in the transformation that is needed to achieve this.

The largest source of greenhouse gas emissions worldwide is from energy generation and usage, generation of electricity from fossil fuels or burning fossil fuels for heat or mobility. In Hong Kong, approximately 70% of our greenhouse gas emissions come from electricity generation, and 90% of this electricity is used in buildings. Hence the importance of a focus on reducing electricity usage in buildings.

However, energy efficiency is not only important for mitigating climate change. It is also important for energy security and stability around the world. Excessive demand for energy will be a source of conflict and instability.

The evidence reflected in this Guide shows that in Hong Kong, like elsewhere, there is considerable scope for businesses to work more ambitiously to reduce their energy usage. This can be done in a way that works for business and the economy: costs can be reduced and innovation and new technologies supported. We see enormous potential for improvement for the benefit of Hong Kong in terms of efficiency and in generating the expertise to make the most of new business opportunities, for example along the Belt & Road.

To make rapid and meaningful change, collaboration by businesses and experts to share experience and knowledge is so important. And this project is in our eyes a good example of how businesses through BEC have come together to develop useful and robust guidance.

I hope that this Guide and the Retrofit Calculator published will contribute to Hong Kong's green transformation. The city, in our view, is well-positioned to strengthen its efforts to become a pilot for other metropolitan areas in Asia in sustainable development and our Foundation is pleased to be a partner on this path.

Dr. Peter Hefele

Regional Director

Energy Security and Climate Change Asia-Pacific

Konrad-Adenauer-Stiftung

Overview of the Project

Why commercial buildings?

Climate Change is one of the biggest challenges of the 21st Century, and it is caused by the **emission of greenhouse gases (GHG)**

In Hong Kong, **70%** of GHG emissions are from **electricity generation.** By reducing demand, we reduce GHG emissions

Buildings consume **90%** of the electricity generated, and **more than 60%** of that is used by **commercial buildings**

This Guide contains...

Brief descriptions of **energy-efficient technologies & strategies**

The **cost** and **energy savings**, and **payback periods** for selected technologies & strategies

A comprehensive **step-by-step manual** to our **Retrofit Calculator**

This Guide & Retrofit Calculator is for...

Building Owners
To understand the cost, energy and carbon savings from energy efficient technologies & strategies

Building and Facility Managers
To have an overview of technologies & strategies currently available, and their applicability to various building types

Tenants
To understand how they can benefit from such technologies & strategies, in terms of cost savings and increased comfort levels

Contents

1. Introduction to the Guide

1. Introduction to the Guide

1.1 Purpose of this Guide

This Guide provides users with:

- information on energy saving technologies and initiatives for retrofits of existing office and hotel buildings: costs, energy savings and applicability in different building types
- a Retrofit Calculator with a user-friendly manual.

The aim of the Guide is to support building owners, managers and tenants to make the right decisions and develop a business case for investing in different aspects of the energy efficiency of existing buildings. It gives an overview of desirable initiatives enabling businesses to check what else they may wish to do. The Retrofit Calculator enables approximate costs and energy savings for particular technologies and initiatives in relation to individual buildings to be derived.

Neither the Guide nor the Retrofit Calculator can give precise costs and savings for individual buildings, but this information is a good starting point to commence the process and review progress towards energy efficient retrofitted buildings.

1.2 Scope of the Guide

The Guide covers **offices and hotels** because of their significant energy consumption and contribution to Hong Kong's carbon footprint (Section 4 explains the background in detail). It is aimed at both tenants and landlords of commercial buildings.

It focuses on **retrofits** of existing buildings rather than new buildings which are still to be constructed. This is because the Buildings Energy Efficiency Ordinance (BEEO) Cap. 610[1] already lays down the requirements for new buildings in the Building Energy Code[2]. The Building Energy Code requirements (section 10) also apply to major retrofitting works[3], as defined in the BEEO but because of the relevant size thresholds they are not routinely applied. Those requirements are however also useful as guidance for smaller scale refurbishment.

For ease of reference, we have categorised commercial buildings into 4 types: Office Building Types 1, 2, 3 and Hotel Buildings. This is a simplification of the range of buildings in Hong Kong to enable us to model savings and give approximate indications of savings achievable. Detailed descriptions and assumptions as to these building types are set out in Table 1 below.

When you use the Retrofit Calculator or look at the Marginal Abatement Cost Curves ("MAC curves"), you should do so having regard to the category of building types that the relevant building falls into. It is possible a building will not clearly fall into a particular category, but by looking at the assumptions made as to electrical and mechanical systems, as explained below, it should be possible to establish roughly what savings may be made.

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[1] https://www.elegislation.gov.hk/hk/cap610
[2] http://www.beeo.emsd.gov.hk/en/pee/BEC_2015.pdf
[3] http://www.beeo.emsd.gov.hk/en/mibec_faq_mrworks_a.html#top

Table 1: Categorization of Building Types for the Purpose of the Guide and Retrofit Calculator

Type	Description	Key Aspects of their Electrical & Mechanical Systems
Office Building Type 1	Grade A offices – advanced, modern buildings generally built within the last 30 years, e.g. IFC Office Tower	• Centralised air conditioning system • Variable Air Volume (VAV) system • Water cooled chiller • Tenants will be charged for small power and lighting energy • All system installations, including lighting in common areas, air conditioning, lifts, etc., will be managed by building owners • Tenant area systems such as lighting, lighting controls, high volume low speed fans will be managed and paid for by tenants
Office Building Type 2	Less modern office buildings with centralised air-cooled AC systems, e.g. BEC HQ (Jockey Club Environmental Building)	• Centralised air conditioning system • Fan coil units (FCU) system • Air cooled chiller • Tenants will be charged for small power and lighting energy • All system installations, including lighting in common area, air conditioning, lifts, etc., will be managed by building owners • Tenant area systems such as lighting, lighting controls, high volume low speed fans will be managed and paid for by tenants
Office Building Type 3	Office buildings with no centralised AC system, e.g. older buildings in Wan Chai and parts of Kowloon	• No mechanical fresh air supply • Split type air conditioning units • Tenants will be charged for all electrical consumption including small power, lighting and air conditioning • All system installations to be paid by tenants
Hotel Building	4- or 5-star hotels – modern hotels generally built in the last 30 years	• Centralised air conditioning system • Fan coil units (FCU) system • Air cooled chiller • Centralised boiler for domestic hot water system • All system installations to be paid for by building owner • No tenants

1.3 Structure of the Guide

This Guide is divided into 4 main sections with various sub-sections.

Section 1

- Introduction to the Guide

- Categorization of building types for the purposes of this Guide and Retrofit Calculator

Section 2

- Energy saving initiatives and an overview of their energy and cost saving impact in each building type (Section 2.2)
- Graphical representations of the cost-effectiveness of these initiatives (marginal abatement cost curves), generated from the sample buildings according to our categorization of building types (Section 2.3)
- Directory of Technologies & Initiatives: provides more details on these energy saving initiatives. (Section 2.4)

Section 3

- Step-by-step operation manual from data input to interpretation of output tables (Section 3.1) for the Retrofit Calculator – an easy-to-use excel spreadsheet designed to estimate the costs and energy saving performance for a building with user-customised specifications
- Frequently asked questions about the Retrofit Calculator (Section 3.2)
- Detailed assumptions used in developing the Retrofit Calculator (Section 3.3)
- Current limitations of the Retrofit Calculator (Section 3.4)

Section 4

- Background information
- Importance of this Guide and Retrofit Calculator

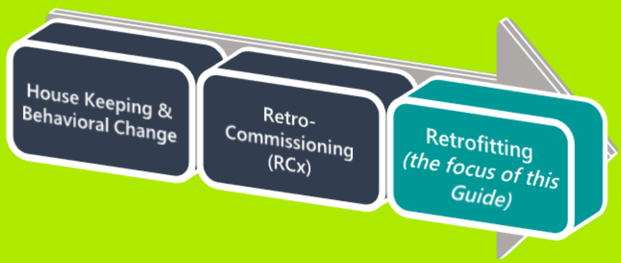
2. Energy Saving Technologies & Initiatives

Construction Industry Council – ZCB
photo courtesy of Ronald Lu & Partners

2. Energy Saving Technologies and Initiatives

3 steps to highly energy efficient buildings

There are 3 main steps that can be taken to improve the energy performance of existing commercial buildings (please see Section 4.7 for more details).



The focus of this Guide is on the third and last step. As retrofitting is the most costly step, building owners and managers need good information before committing capital to a retrofit plan. However, quantitative data as to "proof of performance" is often not available. The Guide and Retrofit Calculator focus on addressing this information gap. They aim to aid you in making informed decisions on retrofits by providing approximate cost and energy savings for common energy efficient equipment. This information is an initial first step, and further work will be needed in projects of a significant size to fully understand costs and savings.

Top tip: Integrate into your refurbishment programme & maintenance schedule

The time that wider refurbishment is being undertaken is the right time for energy efficiency retrofitting. It is a great opportunity to upgrade your system into an energy efficient one at the lowest possible cost. Introducing such technologies may mean slightly higher capital costs than like-for-like replacements initially, but will help you save significant amounts of energy and costs over the life cycles of their operations, as shown in Section 2.3. The labour costs and disruption to occupants will be reduced by integrating upgrades into refurbishment programmes.

2.1 Methodology: Modelling Costs & Savings of Key Technologies and Initiatives

The costs and savings of some of the most common energy efficient technologies in commercial buildings, as listed in Table 2 below, have been modelled according to Hong Kong Performance-based Building Energy Code and Appendix G of ASHRAE 90.1 and adjusted to reflect building operational scenarios. The assumptions for these technologies are listed in Appendix A.

Please note some technologies are usually only replaced when they approach their end-of-life because of their high capital cost, e.g. lifts, but others like office lights may be replaced when still fully functional. Therefore we have categorised each technology replacement into either a "fully functional scenario" or an "end-of-life scenario". For the end of life scenario, we have included only the additional or incremental cost of the more energy efficient replacement technology.

In sub-section 2.2, we set out the top technologies for offices and for hotels with their energy and costs savings, calculated with reference to a sample building. This is followed by a brief description together with cost and energy savings of each technology in Section 2.4.

Table 2: List of technologies/initiatives

Type	No.	Initiative
With costs and saving potentials modelled		
Façade	1	High Performance Glazing#
	2	Solar Control Window Films
Lighting	3	Light-emitting Diode (LED) Lighting (in Landlord Areas)#
	4	Tenant Office Lighting Design to 300lux
	5	Tenant office Lighting Control with Occupancy Sensors
Heating, Ventilation and Air Conditioning (HVAC) – Chiller Plants	6	Seasonal Chilled Water Temperature Reset
	7	Variable Speed Drive (VSD) Chillers#
	8	Oil-free Magnetic Bearing Chillers#
	9	Variable Speed Drives (VSD) on Chilled Water Pumps#
HVAC – Air-side	10	Demand-controlled Ventilation (DCV)
	11	Electronically Commutated (EC) Plug Fans#
	12	Direct Current (DC) Fan Coil Units (FCUs)#
	13	Variable Refrigerant Flow (VRF)#
	14	Intelligent Building Control Systems
	15	High Volume Low Speed (HVLS) Fans
	16	Carbon Monoxide Sensor Controls for Carparks
Lifts	17	Variable Voltage Variable Frequency (VVVF) Lift Drives#
	18	Regenerative Braking Lifts#
Hot Water Supply & Renewable Energy	19	Heat Pumps
	20	Solar Water Heating (SWH) Systems
	21	Solar Pool Heating
	22	Photovoltaics
Initiatives that were NOT modelled		
Others	23	Retro-commissioning (RCx)
	24	High Efficiency Gas Technologies
	25	Radiant Chilled Ceiling Systems (Chilled Beams)
	26	Resizing Pumps
	27	Task Lighting
	28	District Cooling System (DCS)

End-of-life scenarios: these options are generally replaced only at their end-of-life stage.

2.2 Findings Regarding the 4 Building Types

Tables 3 and 4 below show the top initiatives with respect to carbon abatement. To identify these initiatives we created sample buildings (see specifications in Appendix B), one for each building type, and modelled the cost and energy savings that it is reasonable to expect. The full result table is in Appendix C.

Please note: some costs in Tables 3 and 4 are split into landlords' and tenants' savings and may slightly differ from those listed in Appendix C.

The costs for "end-of-life scenario" technologies highlighted in purple are calculated based on incremental costs, the additional cost between a like-for-like replacement and an energy efficient equipment. If the energy efficient equipment is cheaper than the original replacement, we assume they have no costs thus their payback periods would be zero. Costs for other technologies are calculated based on their full costs.

Please note that the payback period and expected costs are calculated based on replacing fully functional existing equipment, unless otherwise specified. If your building equipment has reached its end-of-life and needs replacement, you can expect the actual payback period and expected costs to be lower than what is shown below.

To get a better understanding of costs and energy savings in those circumstances you can refer to our graphs in Section 2.3, or use our Retrofit Calculator explained in Section 3.

For those technologies which have high capital costs, such as lifts, glazing and chillers, we use "end-of-life scenarios", including only the incremental capital cost of the more efficient technology in our calculations. We also show their savings in comparison with a like-for-like replacement at the end-of-life stage, as in practice it would be rare to seek to upgrade those facilities at any other stages.

Table 3: Landlords' Perspective – Top 6 Options with Greatest Carbon Abatement

Landlords' Top 6 Options with Greatest CO_2 Reductions Over Building Lifecycle				
No.	Description	Simple Payback Period [years]	Approximated Cost over Lifecycle*	CO_2 Reductions over Lifecycle [tons]
Type 1 Office Building (Fig. 2)				
10	Fresh air demand control	3.91	-$12,951,980	8,534.62
8	Oil-free Water-cooled Chillers	7.39	-$7,697,576	6,470.35
7	Variable speed drive water-cooled Chillers	5.62	-$6,565,048	4,839.74
2	Solar Control Window Film	13.59	-$820,854	4,618.67
15	High-volume low-speed (HVLS) fans	10.63	-$3,832,295	4,336.91
3	LED lighting in landlord areas	1.29	-$3,678,400	2,625.48
Type 2 Office Building (Fig. 4)				
10	Fresh air demand control	0.56	-$22,598,488	14,376.27
8	Oil-free Water-cooled Chillers	6.05	-$9,248,483	8,198.25
4	Tenant Office Design to 300lux	0.02	-$8,429,773	5,234.46
7	Variable speed drive water-cooled Chillers	7.03	-$5,172,386	4,933.93
15	High-volume low-speed (HVLS) fans	11.52	-$3,199,446	4,668.39
3	LED lighting in landlord areas	1.07	-$4,709,919	3700.92
Type 3 Office Building^ (Fig. 6)				
3	LED lighting in landlord areas	1.31	-$3,587,963	3,007.13
16	Carpark fans with VFD and CO sensor	1.36	-$2,410,275	1,638.86

17	High efficiency lifts	0.00	-$1,634,919	1,010.99
18	Regenerative braking lifts	3.06	-$1,301,586	1,010.99
22	Photovoltaics (PV)	34.57	$758,560	644.00
Hotel Building (Fig. 8)				
8	Oil-free Water-cooled Chillers	5.97	-$28,051,977	21,190.85
7	Variable speed drive water-cooled Chillers	6.03	-$19,345,066	14,679.18
12	DC fan coils	4.51	-$18,211,286	13,808.32
3	LED lighting	0.76	-$18,612,359	11,624.14
9	Variable speed drive chilled water pumps	0.17	-$17,815,928	9,522.58
19	Heat pumps for domestic hot water	4.98	-$11,863,282	8,375.54

* We assumed existing buildings will remain for 20 more years; negative costs represent savings

^ Less than 6 options apply to landlords for Office Building Type 3

Table 4: Tenants' Perspective – Top 3 Options with Greatest Carbon Abatement

Tenants' Top 3 Options with Greatest CO_2 Reductions Over Building Lifecycle				
No.	**Description**	**Simple Payback Period [years]**	**Expected Cost over Lifecycle***	**CO_2 Reductions over Lifecycle [tons]**
Type 1 Office Building^ (Fig. 2)				
4	Tenant Office Lighting Design to 300lux	0.05	-$10,974,959	5,872.91
5	Tenant Office Lighting Control with Occupancy Sensors	2.07	-$3,289,081	2,197.80
Type 2 Office Building (Fig. 4)				
4	Tenant Office Lighting Design to 300lux	0.03	-$16,512,660	10,276.11
5	Tenant Office Lighting Control with Occupancy Sensors	1.38	-$5,366,551	3,848.75
12	DC fan coils	5.77	-$3,565,839	3,584.31
Type 3 Office Building (Fig. 6)				
4	Tenant Office Design to 300lux	0.03	-$23,353,701	14,528.13
13	VRF or high efficiency split type	3.82	-$7,277,036	9,892.95
5	Tenant Office Lighting Control with Occupancy Sensors	0.98	-$7,895,974	5,412.88
Hotel Building – not applicable as hotel customers are not tenants				

* We assumed existing buildings will remain for 20 more years; negative costs represent savings

^ Less than 3 options apply to tenants for Office Building Type 1

Note: Tenants should also consider replacing lighting in their rented premises with LEDs as this would lead to high carbon abatement with a good payback, similar to replacement in landlord areas.

2.3 A Visual Representation of Energy and Carbon Savings [Marginal Abatement Cost Curves]

Using the above outputs (shown in full at Appendix B & Appendix C), we have generated graphs, also known as marginal abatement cost curves ("MAC curves"). They are able to help readers understand at a glance the relative cost and energy savings of different technologies and initiatives.

The graphs also show which energy saving options have large energy saving/carbon abatement effects and can pay for themselves in their lifetime. A simplified example of the graphs generated is shown below.

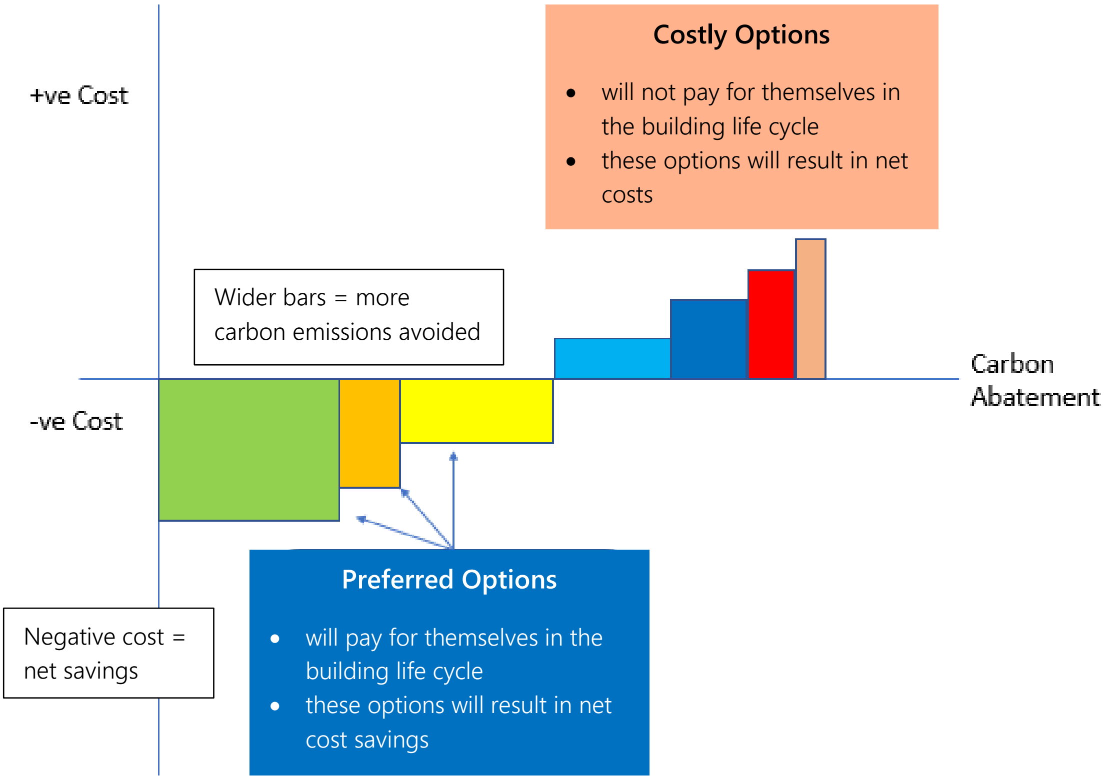


Figure 1: A Sample Marginal Abatement Cost Curve

The x-axis represents the carbon emissions avoided in the full life cycle of a building (we assumed 20 years): the wider the box, the more carbon will be saved. The y-axis shows the net total cost of the energy saving option that includes equipment cost, installation cost, and cost savings from reduced energy use: if a box is below the x-axis, that particular energy saving option will be able to pay for itself and generate additional cost savings; if a box is above the x-axis, the option will not pay for itself in the remaining lifetime of the building at current equipment/installation and energy costs.

This does not mean that you should not take actions above the x-axis, as reducing carbon emissions is not only about saving money. More extensive use of certain technologies may also lead to equipment and installation costs coming down, and it may be that energy costs will increase leading to some of the technologies above the line becoming net positive in terms of cost or at least cost neutral in the near future. The 4 graphs for each building type are shown below.

Distinction between End-of-Life Replacement Scenarios and other Scenarios

The costs of retrofits, unless otherwise specified, are calculated based on replacing fully functional existing equipment. The MAC curves calculated with **full costs** are labelled as "**Replacement within lifetime scenario**" (Figures 3, 5, 7 & 9).

As technologies like lifts or chillers have high capital costs, in practice it would be rare to seek to upgrade those facilities at any stage other than the end-of-life stage. Therefore additional MAC Curves (Figures 2, 4, 6 & 8), labelled "**showing costs savings in end-of-life replacement scenario**", have been added to reflect this. These MAC curves for end-of-life options, highlighted in **purple**, are calculated using **incremental costs**, the additional cost between a like-for-like replacement and a more energy efficient replacement.

The technologies that we consider would generally only be replaced at "end-of-life" are listed below:

- **High performance glazing**
- **LED lighting in landlord areas**
- **Variable speed drive water-cooled chillers**
- **Oil-free water-cooled chillers**
- **Variable speed drive chilled water pumps**
- **Electrically commutated plug fans**
- **Direct current fan coil units**
- **Regenerative braking lifts**
- **Variable voltage variable frequency lifts**
- **Variable refrigerant flow**

Please note: The MAC curves below are updated due to adjustments in the costing information, and may be slightly different from the old MAC curves used in our introductory booklet.

Type 1 Office Building – showing cost savings in end-of-life scenario for high capital cost technologies and within lifetime for others

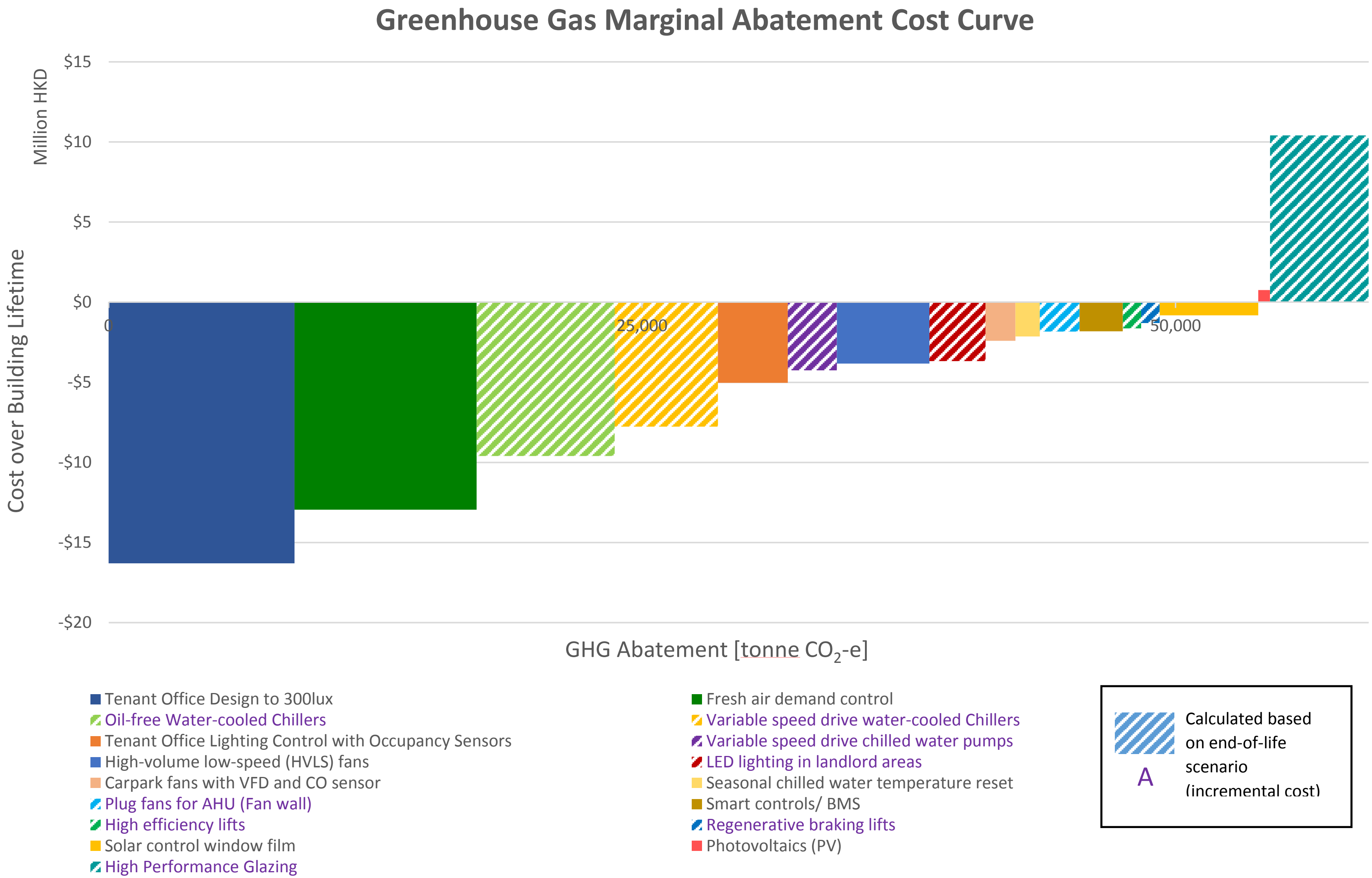


Figure 2: MAC Curve for Type 1 Office Building with End-of-life Options, Calculated with Incremental Cost

Type 1 Office Building – showing cost savings in replacement within lifetime scenario

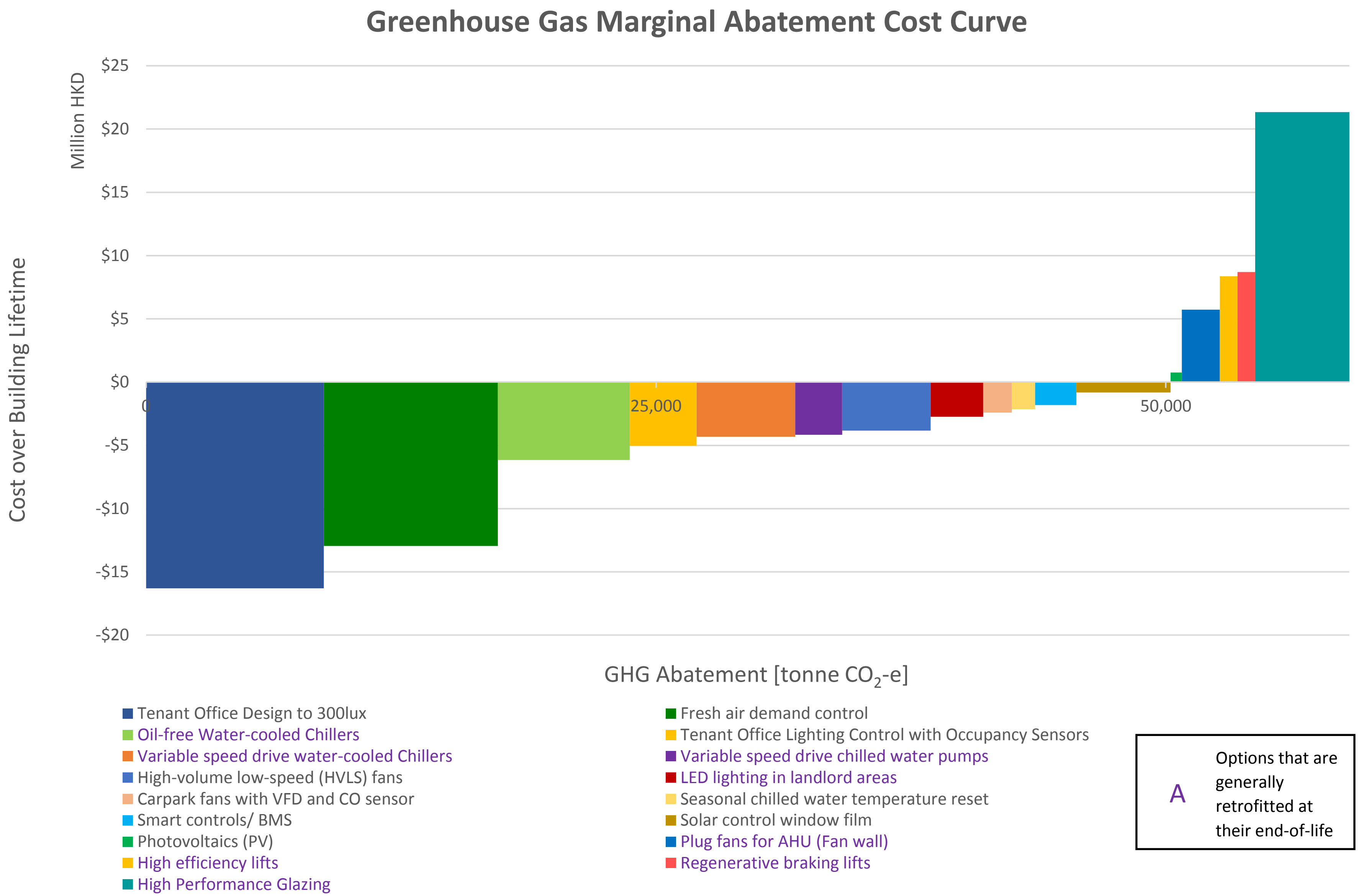


Figure 3: MAC Curve for Type 1 Office Building with End-of-life Options, Calculated with Total Cost

Type 2 Office Building – showing cost savings in end-of-life scenario for high capital cost technologies and within lifetime for others

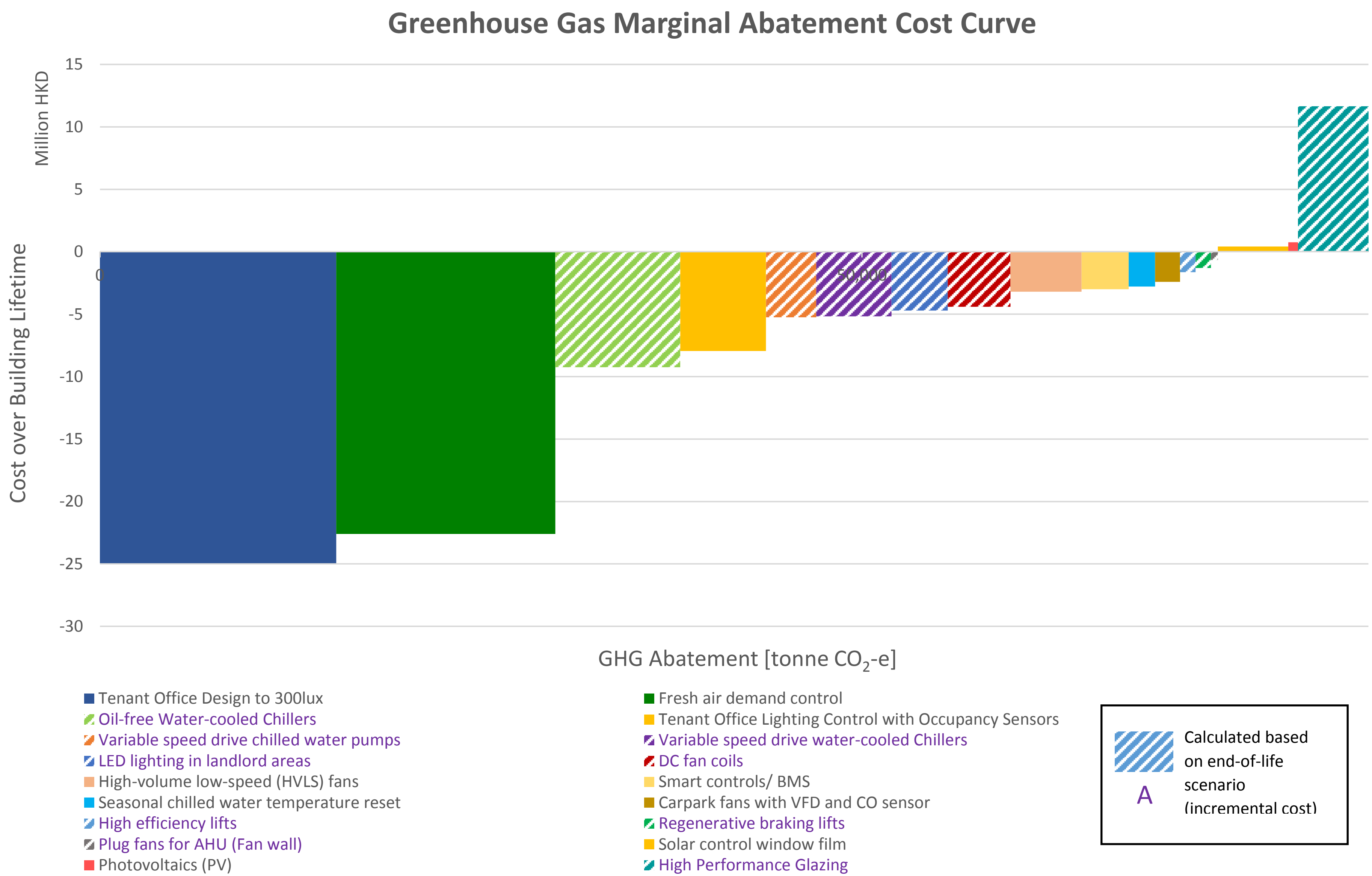


Figure 4: MAC Curve for Type 2 Office Building with End-of-life Options, Calculated with Incremental Cost

Type 2 Office Building – showing cost savings in replacement within lifetime scenario

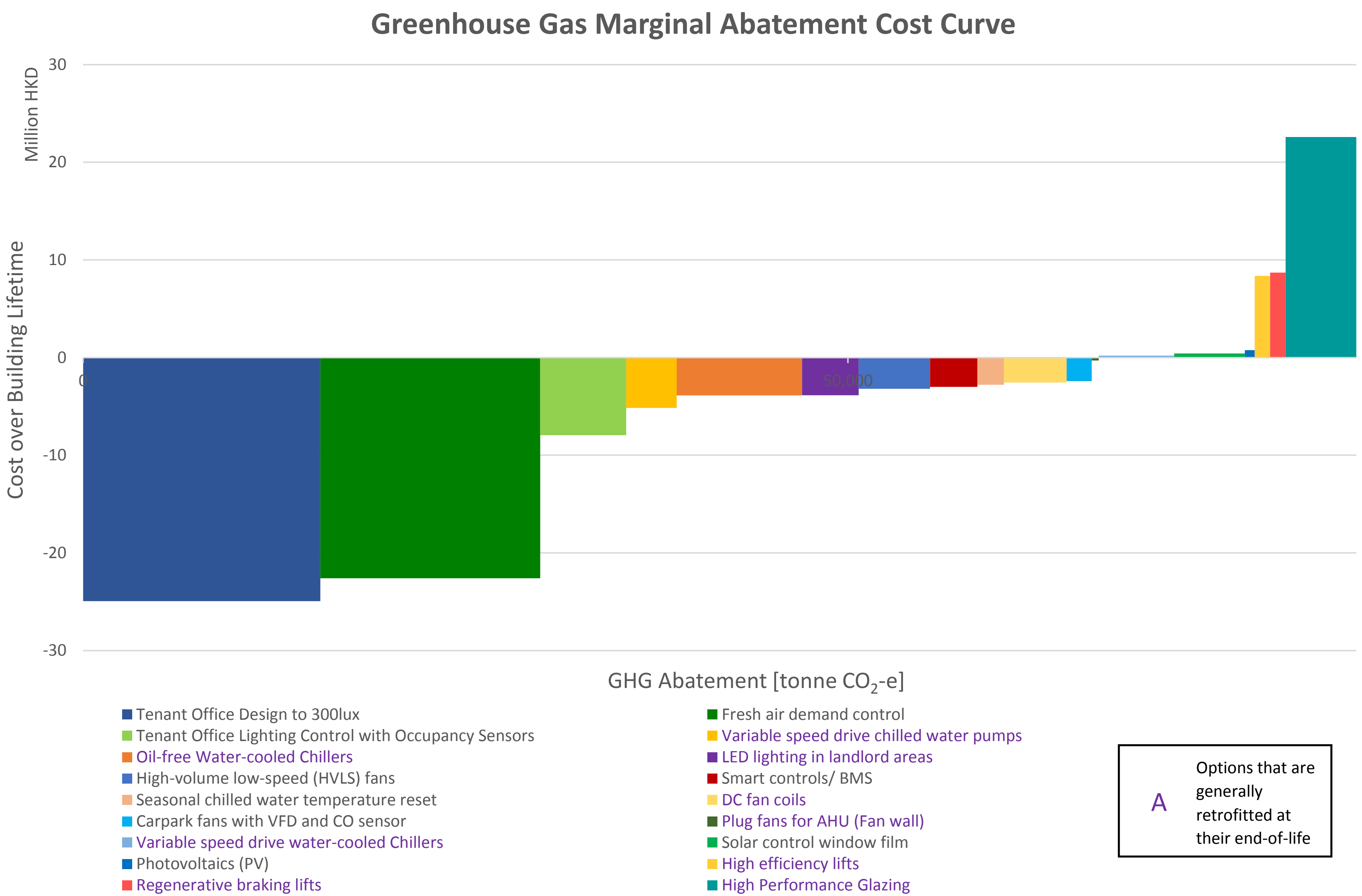


Figure 5: MAC Curve for Type 2 Office Building with End-of-life Options, Calculated with Total Cost

Type 3 Office Building – showing cost savings in end-of-life scenario for high capital cost technologies and within lifetime for others

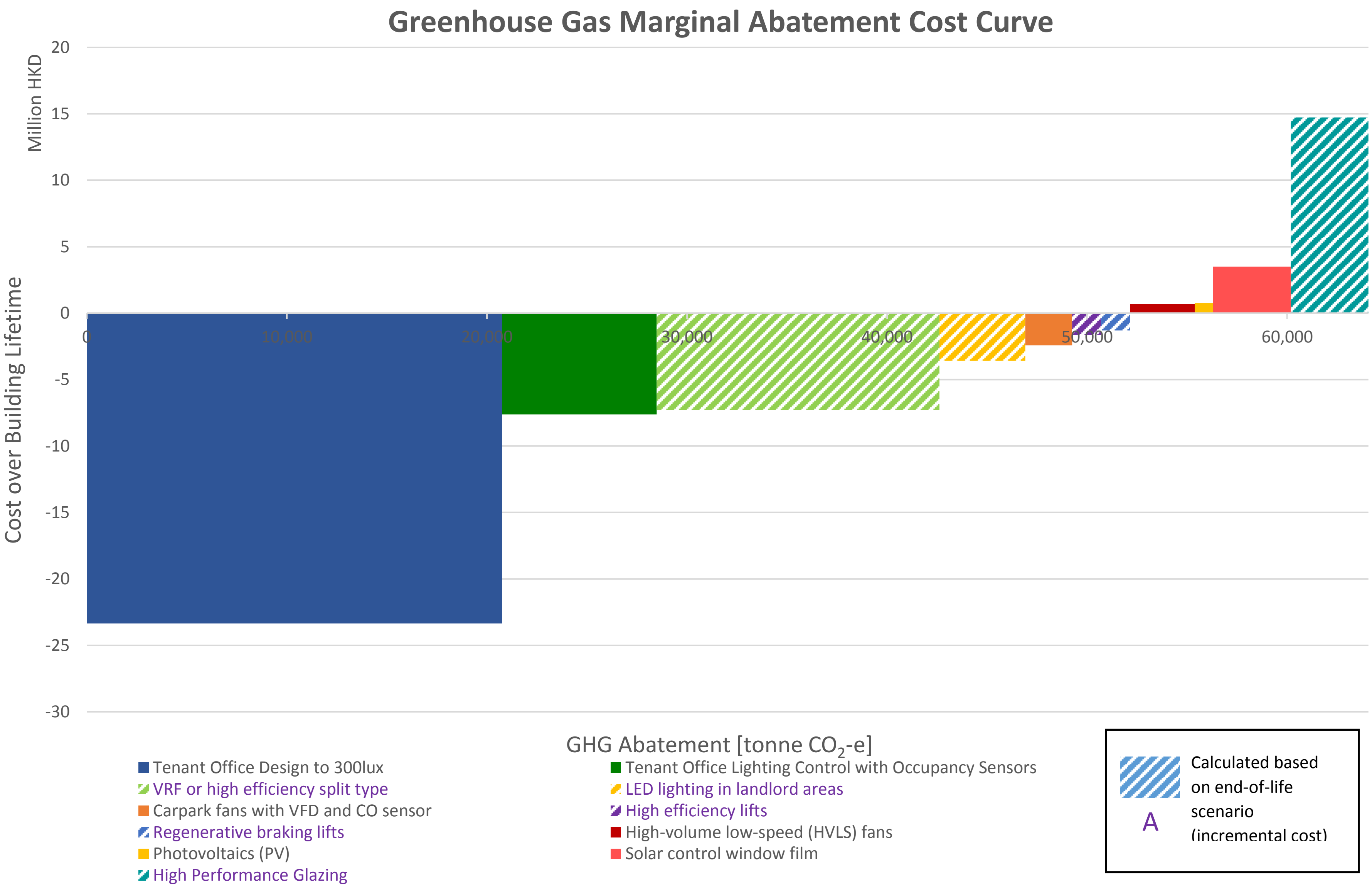


Figure 6: MAC Curve for Type 3 Office Building with End-of-life Options, Calculated with Incremental Cost

Type 3 Office Building – showing cost savings in replacement within lifetime scenario

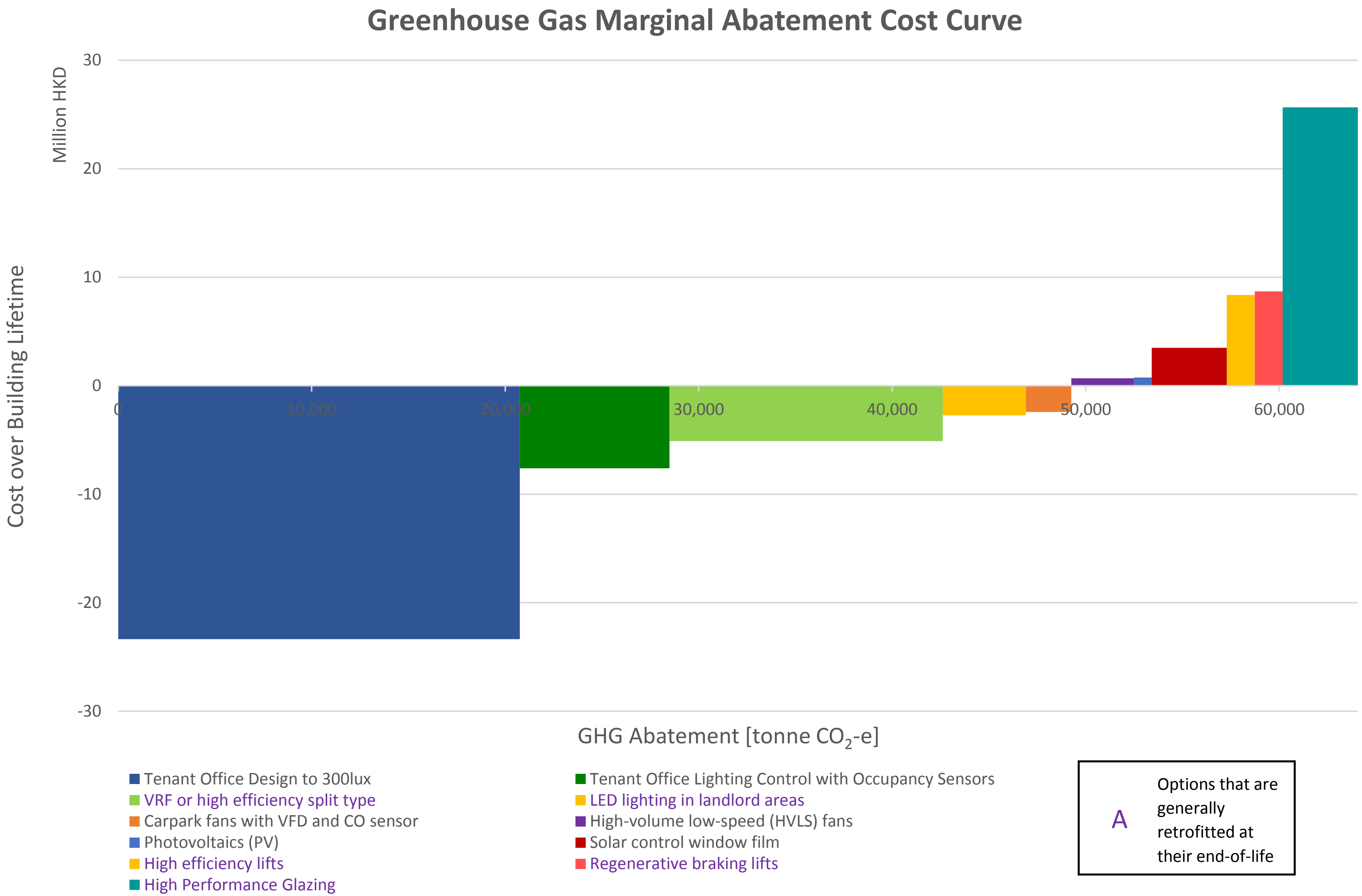


Figure 7: MAC Curve for Type 3 Office Building with End-of-life Options, Calculated with Total Cost

Hotel Building – showing cost savings in end-of-life scenario for high capital cost technologies and within lifetime for others

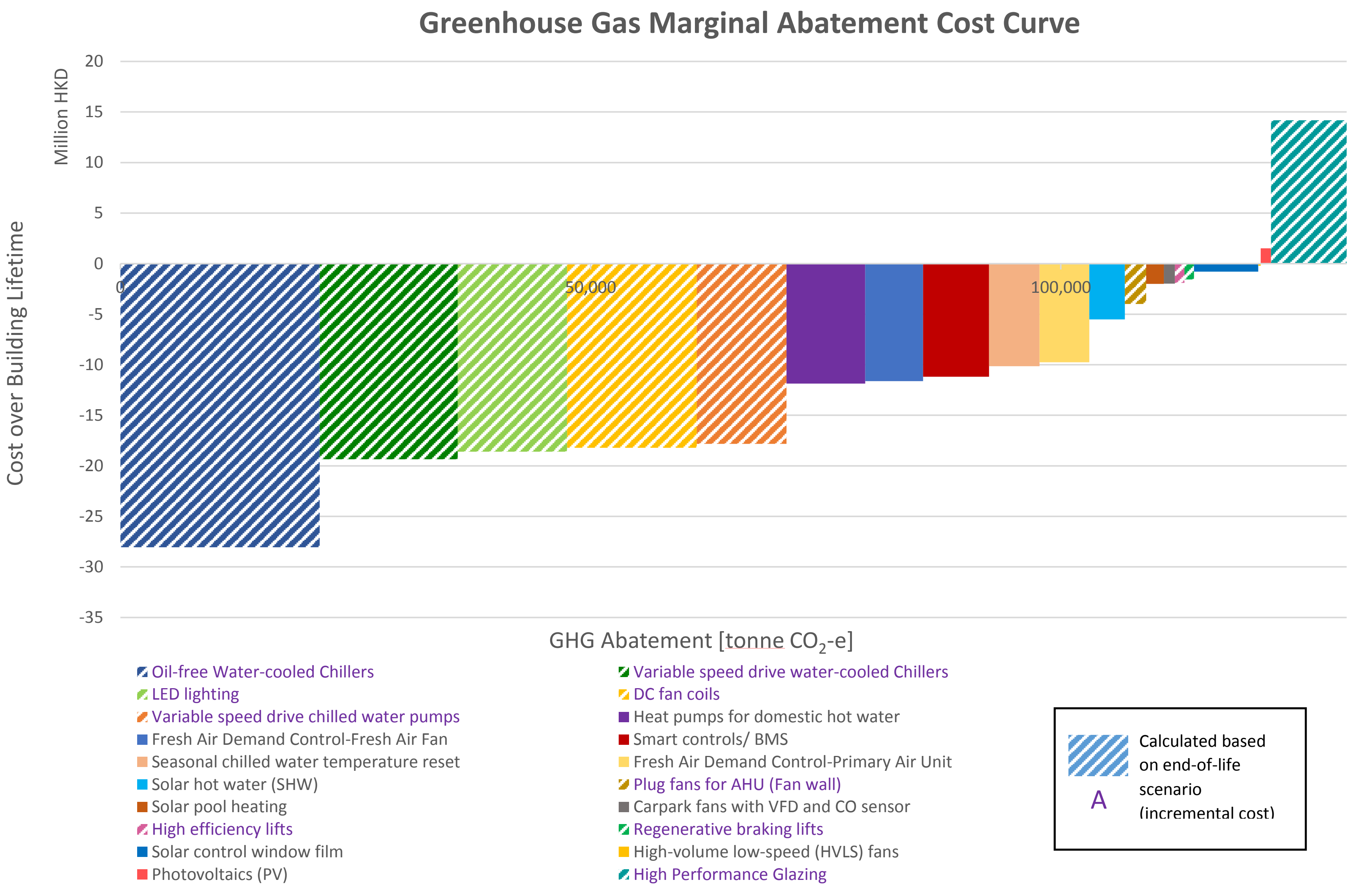


Figure 8: MAC Curve for Hotel Building with End-of-life Options, Calculated with Incremental Cost

Hotel Building – showing cost savings in replacement within lifetime scenario

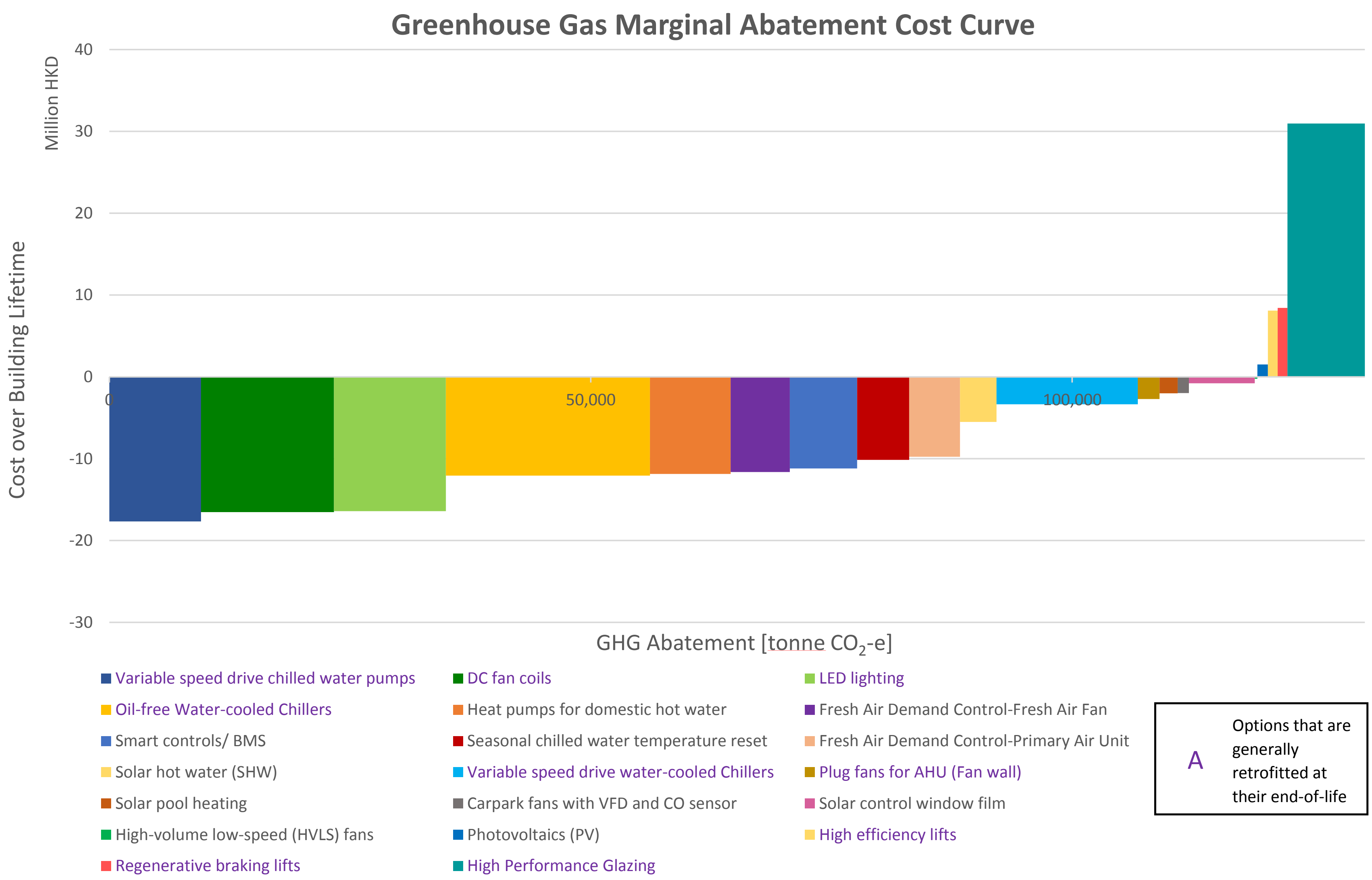
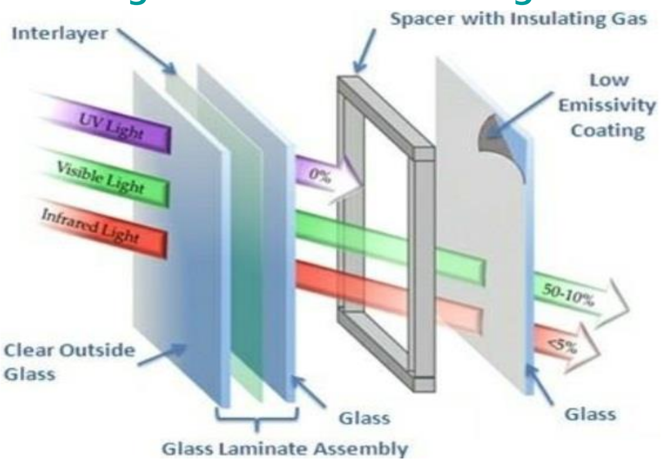


Figure 9: MAC Curve for Hotel Building with End-of-life Options, Calculated with Total Cost

2.4 Energy Saving Technologies and Initiatives: A Directory
How much can you save? When are they most impactful?

2.4.1 High Performance Glazing



Source: Suntuitive Self-tinting Glass

Why?

- improves energy performance, thermal comfort and access to daylight
- long life cycle and minimal maintenance

Where does it work best?

Office Buildings (Types 1, 2 & 3)

Hotel Buildings

Overview

Windows are a major source of heat gain and heat loss and can bring visual and thermal discomfort. High performance glazing helps reduce energy use in heating or cooling by minimizing heat transfer. There are a number of types of high performance glazing: multiple glazing (i.e. double or triple glazing), specialised transparent coatings, insulating gas between panes (an enhanced form of multiple glazing), or improved frames[4]. A comparison of different glazing options can be found on EMSD's website[5].

In this guide we modelled double glazed windows with low-emissivity (low-e) coatings. Double glazed windows have two panes of glass separated by an air gap that insulate premises from both noise and heat transfer. Low-e coating allows the visible range of the solar spectrum to enter the building while reflecting the infrared range (some can also reflect the ultraviolet range).

This means the interior of a building receives sufficient amounts of lighting without gaining much heat from solar radiation. Less energy is consequently needed to keep the interior cool.

Advantages

- technology is mature
- can improve energy performance, thermal comfort and access to daylight
- long life cycle and easy maintenance
- reduced noise levels

Limitations

- high retrofitting costs which make this very expensive unless a new façade replacement is needed

[4] http://gbtech.emsd.gov.hk/english/minimize/green_windows.html
[5] http://www.energyland.emsd.gov.hk/en/building/energy_use/envelope.html

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Double Glazing with Low-E Coating									
Building Type		Office						Hotel	
		Type 1		Type 2		Type 3			
Type of Scenario		End-of-Life	Total Cost	End-of-Life	Total Cost	End-of-Life	Total Cost	End-of-Life	Total Cost
Capital Cost (per m^2 of façade glazing) (HKD)		$4,200	$6,600	$4,200	$6,600	$4,200	$6,600	$4,200	$6,600
Payback Period (years)		43.9	69.0	51.2	80.4	87	136.7	39	61
Saving Potentials (per m^2 of building floor area)	Cost	HK$22/year		HK$19/year		HK$11/year		HK$14/year	
	Energy	19 kWh/year		17 kWh/year		10 kWh/year		13 kWh/year	
	Carbon	12 kg CO_2-e/year		10 kg CO_2-e /year		6 kg CO_2-e /year		8 kg CO_2-e /year	

Additional Considerations

- upgrading to double glazing has an additional benefit of reduced noise transmission
- double/triple glazed insulating glass units (IGU) can be applied to protect low-e coatings
- high performance glazing would be much more cost-effective if the façade of the building needs to be replaced as a part of building renovations
- a cheaper option would be to install window blinds, but this is less effective as solar radiation would still enter the building through windows

Relevance to Landlords and Tenants

- glazing systems are a part of building envelope installation, so replacement would generally be paid for by landlords
- generally, reduction in cooling energy in tenant spaces will result in cost savings for the landlord, as tenants simply pay a fixed charge that covers cooling amongst other things
- therefore this technology will be directly financially beneficial to the landlord, unless tenant pays for actual cooling (as assumed in Type 3 offices). Tenant should however benefit in comfort terms and in the longer term possibly financially too.

2.4.2 Solar Window Control Film

Source: 3M Sun Control Window Film

Why?

- relatively low cost
- reduce building cooling load

Where does it work best?

Office Buildings (Types 1, 2 & 3)

Hotel Buildings

Overview

A building façade has a long life cycle, so replacing glazing in a building can be very expensive. An alternative way is to fit solar films onto existing glazing. The working principle is similar to high performance glazing: the film reflects a selected spectrum of solar radiation (typically UV and Infrared) out of buildings, to reduce unwanted heat and air-conditioning demand.

In addition to energy savings, the film can also reduce glare and perceived solar radiation, improving visual and thermal comfort of occupants. Solar control window films can be applied to any glazing areas. They are most appropriate for areas with unwanted excessive solar heat gain, such as west facing windows or skylight roofs.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Solar Film

Building Type		Office			Hotel
		Type 1	Type 2	Type 3	
Capital Cost (per m^2 of facade glazing)		HK$1,300	HK$1,300	HK$1,300	HK$1,300
Payback Period (years)		13.6	15.8	26.9	14.1
Saving Potentials (per m^2 of building floor area)	Cost	HK$22/year	HK$19/year	HK$11/year	12 HK$/year
	Energy	19 kWh/year	17 kWh/year	10 kWh/year	11 kWh/year
	Carbon	12 kg CO_2-e/year	10 kg CO_2-e /year	6 kg CO_2-e /year	6 kg CO_2-e /year

Advantages

- relatively low cost, and can be applied in different phases for cost considerations
- reduce building cooling load
- improve thermal and visual comfort in areas with direct sunlight exposure

Limitations

- glazing transparency will be reduced so less daylight will be received indoors

- may increase building albedo and produce more external glare
- not as durable as embedded systems (high performance glazing)
- may not be very effective for buildings that receive limited amounts of solar radiation, e.g. buildings that are shaded throughout the day by their surrounding buildings

Additional Considerations

- manufacturers' advice should be considered
- solar control films can be installed in small areas as a trial before a full-scale implementation
- the colour and reflectance of external glazing may be altered

Relevance to Landlords and Tenants

- installation of solar films involves work on the building façade, which would primarily be the responsibility of the building owner
- generally, reduction in cooling energy in tenant spaces will result in cost savings for the landlord, as tenants simply pay a fixed charge that covers cooling amongst other things
- therefore this technology will be directly financially beneficial to the landlord, unless tenant pays for actual cooling (as assumed in Type 3 offices). Tenants should however benefit in comfort terms and in the longer term possibly financially too.
- increased lighting costs would be borne by tenants

Case Study – Solar Film Treatment

In 2014, the glass façade of a lobby area of a residential complex in Tai Kok Tsui was treated with solar film.

The lobby faces southwest, with the front of the glass exterior façade being approximately 18 meters in width and three-story in height. The façade already had low-e glass and double glazing designs in place. However, during summer and periods of intense direct solar radiation, the temperature of certain areas of the lobby would still reach uncomfortable levels, despite the air conditioning system operating as usual. Solar film was applied to the glass facade to further reduce solar heat gain. The process of applying solar film to the entire façade took approximately 3 weeks.

On average, the ambient temperature of the lobby was reduced by 3 degrees Celsius after the solar film treatment, compared to before its application.

Information provided by SHKP and its property management subsidiaries

2.4.3 Light-emitting Diode (LED) Lighting (in Landlord Areas)

Source: Lighting 4 Diamonds T8 LED Showcase Lighting

Why?

- significant energy savings
- does not need to modify the existing system

Where does it work best?

Office Buildings (Types 1, 2 & 3)

- open plan office areas
- core areas such as fire escapes

Hotel Buildings

- back-of-house office areas
- cove lighting

Overview

Light-emitting diodes (LEDs) have significantly higher efficiency than incandescent lamps. Newer LEDs are also more efficient than fluorescent lamps, as LEDs convert electric energy more efficiently to light energy.

There are various types of LED lamps, and certain LED tubes can fit into existing fluorescent fixtures, with almost no disruption to the building occupants. This Guide specifically focuses on retrofitting replacement lamps for T8 fluorescent tubes, as T8 tubes are common in older Type C office buildings, and some back of house (BOH) hotel areas.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Retrofitting LED T8 Tubes					
Building Type		Office Types 1, 2 & 3		Hotel	
Scenario		End-of-Life	Total Cost	End-of-Life	Total Cost
Capital Cost (per m^2 of building area)		HK$16	HK$27	HK$16	HK$25
Payback Period (years)		1.3	2.2	0.8	1.3
Saving Potentials (per m^2 of building area)	Cost	HK$12/year		HK$21/year	
	Energy	11 kWh/year		18 kWh/year	
	Carbon	6 kg CO_2-e/year		11 kg CO_2-e/year	

Advantages

- LED technology has advanced and become mature
- quality LEDs have similar lighting quality to fluorescent T5 & T8 tubes
- significant energy savings
- available for direct replacement, so no extra efforts needed to modify the existing system
- greater reliability as LED tubes have longer lifetimes than fluorescent tubes
- modern LED systems have embedded functions like occupancy sensors and remote controls, that can be easily integrated into automated control systems

- additional energy savings from reduced cooling load
- higher energy efficiency as a directional light source
- cheaper than retrofitting to T5 lamps, which requires an upgrade of the entire fitting

Limitations

- toxicity hazard from the disposal of LEDs, as they may contain lead and arsenic
- initial cost of LED tubes would be higher than T5 & T8 tubes

Additional Considerations

- in most cases, retrofits are simple and no other changes are required:
  - if a **magnetic** transformer is used, it does not need to be replaced
  - if an **electric** transformer is used, it will need to be bypassed and will require an electrician plus additional installation time
- you can also retrofit the existing wiring for LED luminaires that will be more cost effective in the long run, with extended lifetime and increased efficiency
- projects should consider dimming needs for LED lamps and check whether the compatible drivers are installed to support this

Relevance to Landlords and Tenants

- switching to LED lighting can be done by both landlords and tenants – shared areas and individual premises - and will therefore result in cost savings for both
- only landlord savings – for shared areas - are calculated in the Retrofit Calculator, as tenants are usually restricted by reinstatement clauses that discourage improvements in their rented premises.

Case Study – LED Lights

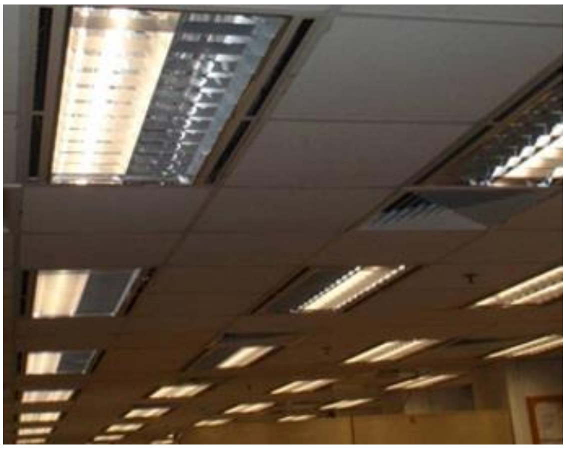
In 2014, 49 T8 light fixtures were replaced with LED panels in the public area of one floor of an office building in Kowloon Tong. Of the 49 light fixtures, 14 are essential lighting panels operating 24 hours per day throughout the week, 29 non-essential lights at the corridor operating 12.25 hours per day on weekdays, and 6 were non-essential lights in toilets operating at 13.75 hours per day during weekdays and 9.5 hours on Saturdays.

Since the retrofit work took place in the public area of the office building, disturbance to building occupants was not severe. Efforts were made to further reduce the disturbance to building occupants such as by scheduling retrofit works to take place on weekends and holidays.

The replacement of T8 fixtures with LED panels led to a reduction of electricity consumption from lighting by 57%, and an annual energy saving of more than 9,800 kWh. The energy savings translated to a payback period of approximately 3.5 years. If all of the light fixtures were to operate at 24 hours per day, the corresponding payback period would be even shorter.

Information provided by Business Environment Council

2.4.4 Reduced Illuminance to 300lux



Source: The Give Grid

Why?

- easy implementation
- low cost with significant savings

Where does it work best?

Office Buildings (Types 1, 2 & 3)

- open plan office areas

Hotel Buildings

- back-of-house office areas

Overview

Lighting systems in buildings are often designed to be much brighter than needed. As office work used to be heavily reliant on paperwork, 500 lux was considered to be the appropriate illuminance level in the past. However, modern offices often operate with computer systems, so 300 lux will be adequate for the majority of offices[6].

Energy used for lighting is directly proportional to illuminance levels. By reducing the illumination level from 500 lux to 300 lux, significant energy can be saved. The easiest way to reduce illuminance is to simply replace existing light tubes with lower output ones, or delamp the lighting systems (for instance, remove 1 light tube for fittings with multiple light tubes). Better effects can be achieved by modifying the entire lighting layout and light fittings, but this would mean higher capital costs.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Reduction to 300 lux by retrofitting to lamps with lower output*		
Capital Cost (per m^2 building area)		HK$2*
Payback Period (years)		0
Saving Potentials (per m^2 building area)	Cost	HK$41/year
	Energy	36 kWh/year
	Carbon	22 kg CO_2-e/year

* Reducing illuminance to 300 lux by delamping would not incur any capital cost

Advantages

- straightforward implementation, and original light fittings can be retained
- relatively low capital cost with significant energy savings
- procurement and maintenance costs can be reduced as less light tubes would be needed

[6] https://www.emsd.gov.hk/filemanager/en/content_764/Task_Lighting_Design.pdf

- delamping is reversible – occupants can simply put light tubes back if the illuminance level is insufficient

Limitations

- occupants may need time to adapt to new illuminance levels
- delamping may affect the aesthetic of light fittings
- high capital cost if the entire lighting layout needs to be changed

Additional Considerations

- lighting uniformity needs to be checked after the replacement of lower output lamps or delamping
- reducing illuminance levels can be implemented in conjunction with LED lighting to achieve even greater energy and cost savings
- some tenants may still consider 500 lux to be a standard requirement, so expectation setting or management may be needed
- task lighting (please see Section 2.4.27) can be used to provide supplement for work with high lighting power requirements

Relevance to Landlords and Tenants

- this can be done by both landlords and tenants
- the energy savings from reduced illuminance in tenant areas is primarily beneficial to tenants as they generally pay electricity bills for lighting, however, landlords may benefit from having premises for rental with lower operational costs

2.4.5 Daylight and Occupancy Sensors

Source: Honeywell Wireless Occupancy Sensors

Why?

- significant energy savings
- do not need to modify the existing system

Where do they work best?

Office Buildings (Types 1, 2 & 3)

- open plan office areas and meeting rooms
- enclosed space such as cellular offices, fire escapes, bathrooms, corridors, etc.
- back-of-house office areas

Hotel Buildings

- back-of-house office areas

Overview

Daylight sensors can modulate lighting levels in response to the strength of sunlight indoors, and maintain the required illuminance levels. These sensors can be installed in lighting zones located near windows or skylights.

Occupancy sensors work in a similar fashion: they detect the presence of occupants in a room using infrared and/or ultrasonic technology, and switch off or dim down (e.g. to 20% of the original lux levels) the lamps when the zone is unoccupied.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Occupancy Sensors (not modelled for hotels)		
Capital Cost (per m^2 building area)		HK$29
Payback Period (years)		1.9
Saving Potentials (per m^2 building area)	Cost	HK$15/year
	Energy	14 kWh/year
	Carbon	8 kg CO_2-e/year

Advantages

- technology is mature
- significant energy savings when combined with dimmable lighting and daylight access
- reduced lamp usage and also frequency of replacements
- does not require behavioural change

Limitations

- daylight sensors are only effective for areas with daylight access
- dimming controls for lighting will likely require an upgrade of the control electronics (ballast), resulting in additional costs
- users may not be accustomed to intermittent lighting from occupancy sensors with motion control

Additional Considerations

- wiring cost will be a major cost component and installation, therefore needs to be carefully planned combining with more extensive redecoration/refurbishment if possible
- utilizing 2-in-1 (daylight and occupancy) sensors, and sharing sensors between 2 to 3 light fittings can reduce wiring costs while still maintaining good zoning control
- some LED lighting systems have built-in sensors, that may save capital costs and installation time
- occupancy sensors need to be used with caution to avoid health & safety issues, for instance they will not be suitable for HVAC plant rooms; but they can also be wired to switch off part of (e.g. 50%) the lighting system through dual circuit designs
- delay timers can be used with occupancy sensors to reduce unwanted nuisance or avoid over-sensitivity

- wiring flexibility can be improved by assigning each lighting fixture an individual IP address, but would cost significantly more than a local control system that only requires simple wiring
- the 2015 Edition of Building Energy Code has minimum requirements for lighting installations, including daylight controls and automatic timers, so projects undergoing major retrofit works will be required to comply with these conditions

Relevance to Landlords and Tenants

- daylight sensors will result in cost savings for tenants when installed in tenant's premises
- occupancy sensors can be installed in shared areas and individual premises, thereby reducing energy costs for both tenants and landlords

Case Study – Lighting Occupancy Sensors

In 2014, occupancy sensors were installed at the toilets of one floor an office building in Kowloon Tong installed. There are both essential and non-essential LED panel light fixtures at the toilets, and 4 occupancy sensors were installed to control 5 non-essential lights. Essential lights are turned on 24 hours a day throughout the week, while prior to the retrofit, non-essential lights were switched on within the daily opening schedule of the building through a timer. That is, non-essential lights operate for 13.75 hours per day during weekdays and 9.5 hours on Saturdays. With the occupancy sensors installed, non-essential lights turns on upon sensing an occupant, then turns off if no occupant is detected within the next 5 minutes.

With the installation of occupancy sensors, the electricity consumption of the non-essential lights were reduced by more than 29% and an annual energy saving of close to 186 kWh.

Due to the small scale of this retrofit project, the absolute amount of energy saved was limited and the initial costs were relatively large compared to the savings accrued. This is attributed to the lights originally operating on a non-essential schedule already, and each sensor controls a small number of light fixtures. In other words, energy savings could have been enhanced if more light fixtures were controlled per occupancy sensor.

Information provided by Business Environment Council

Case Study 2 – Lighting Occupancy Sensors

In 2015, lighting occupancy sensors were installed in 150 refuse rooms in a residential complex in Tai Kok Tsui. In each room, one sensor controls two T5 light fixtures. Approximately an hour was required to install each sensor in the rooms.

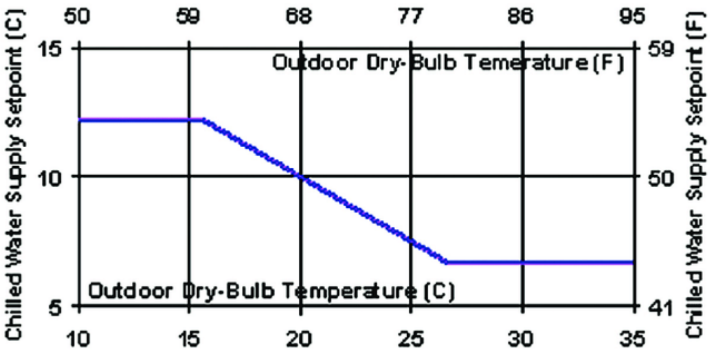
There is one refuse room on every story within the buildings, at which 3 to 4 apartment units on each floor. Given that the number of occupants on each floor is not high, and that building occupants take little time to dispose refuse into waste receptacles and recycling bins, the refuse rooms are often unoccupied.

Prior to installing occupancy sensors, lights in the refuse rooms were switched on permanently – 24 hours a day. After occupancy sensors were installed, lights in the refuse rooms on average switch on for 30 minutes each day. This is a 98% reduction in time which the lights are turned on. With the occupancy sensors, it is estimated that more than 2,900 kWh is saved monthly, compared to prior to the sensors' installation.

Information provided by SHKP and its property management subsidiaries

2.4.6 Seasonal Chilled Water Temperature Reset

Source: ASHRAE



Why?

- relatively low cost
- reduces building cooling load

Where does it work best?

Office Buildings (Types 1 & 2)

Hotel Building

Overview

Raising the chilled water temperature increases the chiller plant performance, reduces the cooling output, and increases the supply air temperature of the cooling delivery terminal units. For a typical 7°C -12°C chilled water system, the energy consumption can be reduced by 5% when the supplied water temperature is increased from 7°C to 8°C, or even up to 10% if the temperature is raised to 9°C.

Chilled water temperature reset will not face any physical constraints as equipment does not need to be replaced. However, there could be a potential reduction in cooling capacity, and an increase in supply air temperatures for certain equipment. After the reset, the capacity of terminal units could be reduced by roughly 10% to 20%, which means, to achieve the same cooling load, they will need to run for longer durations.

The energy savings will be largest during spring and autumn, where maximum cooling is not required, and at sites that require cooling in winter. The temperature reset can be done manually by a facilities manager, or automatically through the building management system (BMS).

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Seasonal Chilled Water Temperature Reset

Building Type		Office		Hotels
		Type 1	Type 2	
Capital Cost (per m^2 building area)		1	1	0.3
Payback Period (years)		0.1	0.1	0.0
Saving Potentials (per m^2 building area)	Cost	5 HK$/$m^2$/year	7 HK$/$m^2$/year	9 HK$/$m^2$/year
	Energy	5 kWh/m^2/year	6 kWh/m^2/year	8 kWh/m^2/year
	Carbon	3 kg CO_2-e/m^2/year	4 kg CO_2-e/m^2/year	5 kg CO_2-e/m^2/year

Advantages

- significant energy savings, as chillers represent a significant proportion of energy consumption
- zero cost for buildings with building management systems or chiller controls in place

Limitations

- the dehumidification performance will decrease for buildings that rely on chillers for humidity control
- may not be suitable for buildings that require constant temperatures, such as data centres or industrial processing plants
- could be expensive if a new chiller or BMS is involved
- frequent monitoring needed, especially in manual operations

Additional Considerations

- may need to check tenants' requirement on chilled water temperatures
- this can be an energy saving opportunity in a retro-commissioning study

Relevance to Landlords and Tenants

- landlords are responsible for central chiller plant upgrades
- cost savings from reduced chiller plant energy use are directly financially beneficial to landlords

2.4.7 Variable Speed Drive ("VSD") Chillers

Source: York

Why?

- high coefficient of performance (COP) at part-load conditions
- the capital cost has been decreasing as technology matures

Where do they work best?

Office Buildings (Types 1 & 2)

Hotel Buildings

Overview

Traditional chillers with constant speed motors in compressors are most efficient at peak load, but have reduced efficiency as the load ratio drops. They run at maximum speed until the thermostat sensor shuts off the machine, and then turn it back on when the room heats up again. This constant on-and-off process both wastes energy and increases wear and tear.

VSD chillers are able to change the speed of compressors to maintain the temperature of the chilled water. They are more efficient at part-load conditions than traditional constant speed chillers, and as efficient at peak load. Provided that chillers operate at part-load more than 90% of the time, VSD chillers can improve energy performance in air conditioning significantly.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

VSD Water-Cooled Chiller							
Building Type		Office Type 1		Office Type 2		Hotel	
Scenario		End-of-Life	Total Cost	End-of-Life	Total Cost	End-of-Life	Total Cost
Capital Cost (per m^2 building area)		HK$68	HK$241	HK$140	HK$409	HK$156	HK$456
Payback Period (years)		3.0	10.5	7.0	20.5	6.0	17.6
Saving Potentials (per m^2 building area)	Cost	HK$23/year		HK$20/year		HK$26/year	
	Energy	20 kWh/year		18 kWh/year		23 kWh/year	
	Carbon	12 kg CO_2-e/year		11 kg CO_2-e/year		14 kg CO_2-e/year	

Advantages

- the capital cost has been decreasing as technology matures
- significant energy savings
- can be installed in like-for-like replacement situations
- VSD chillers have both air- and water-cooled models

Limitations

- higher capital cost than traditional chillers
- water-cooled chiller plants have additional requirement such as cooling towers, water tanks and associated spacing and structural consideration

Additional Considerations

- VSD chillers will need an additional control logic set-up to be efficient
- water-cooled chillers must be in the Fresh Water Cooling Towers (FWCT) Scheme areas[7]
- the payback period will be a lot shorter when the existing chiller plant reaches its end-of-life and needs replacement

Relevance to Landlords and Tenants

- landlords are responsible for central chiller plant upgrades
- cost savings from reduced chiller plant energy use are directly financially beneficial to landlords, and in the longer term potentially beneficial to tenants

2.4.8 Oil-free Magnetic Bearing Chillers

Source: LG

Why?

- extremely efficient at part-load conditions
- require significantly less maintenance

Where do they work best?

Office Buildings (Types 1 & 2)

Hotel Buildings

Overview

Oil-free chillers are considered to be one of the most cost-effective energy saving technologies. They are air conditioning systems that use magnets to levitate parts that normally require lubrication. This reduces friction between the parts and lowers the energy use compared to a traditional chiller that uses lubricants.

Similar to VSD chillers, the coefficient of performance (COP) of oil-free chillers is very high at part-load conditions, and their peak load efficiency is as good as traditional chillers. Therefore, the key for oil-free chillers is to maximise part-load opportunities. Oil-free chillers are also quieter and have longer plant life due to less vibration and friction of bearings.

[7] http://www.emsd.gov.hk/en/energy_efficiency/fwct_scheme/publications/index.html#da

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Oil-free Magnetic Bearing Chiller							
Building Type		Office Type 1		Office Type 2		Hotels	
Scenario		End-of-Life	Total Cost	End-of-Life	Total Cost	End-of-Life	Total Cost
Capital Cost (per m^2 building area)		HK$130	HK$303	HK$200	HK$469	HK$224	HK$523
Payback Period (years)		4.3	9.9	6.0	14.2	6.0	14.0
Saving Potentials (per m^2 building area)	Cost	HK$31/year		HK$33/year		HK$38/year	
	Energy	27 kWh/year		29 kWh/year		33 kWh/year	
	Carbon	16 kg CO_2-e/year		18 kg CO_2-e/year		20 kg CO_2-e/year	

Advantages

- the capital costs reduced as technology matures, resulting in reasonable payback periods
- significant energy savings as they are extremely efficient at part-load
- require less maintenance in terms of replacing worn bearings and lubricants
- quieter and have longer plant life due to less vibration and friction in bearings
- both air- and water-cooled models are available

Limitations

- higher capital cost than traditional chillers
- require control optimization for maximum efficiency

Additional Considerations

- chiller control is the key for oil-free chiller and this will require very careful control logic planning, with input from manufacturer and site operation team in order to achieve the expected efficiency
- the chiller plant can utilise standby capacity to enable the chiller to operate at part-load conditions for maximum efficiency

Applicability to Landlords/Tenants

- landlords are responsible for central chiller plant upgrades
- cost savings from reduced chiller plant energy use are directly financially beneficial to landlord and potentially beneficial to the tenant in the longer term

Case Study – Oil-free, VSD, Water-cooled Chillers

In 2013, variable speed oil-free centrifugal type water-cooled chillers were installed at the rooftop of an office building in North Point, replacing old air-cooled chillers with evaporative cooling tower.

Prior to the installation in 2013, a feasibility study for the chiller plant upgrade was carried out in 2011 to 2012, assessing the various upgrade options. The key factors of consideration were performance, stability, ease of maintenance, and having a short payback period. The variable speed oil-free centrifugal type water-cooled chillers fulfilled these requirements, and were selected as the retrofit option as they were more advantageous in terms of energy efficiency and payback period, even though the investment cost of the new chillers was 20-30% higher than conventional type chillers.

The new chillers came into full operation in 2014. Compared to the old air-cooled chillers, the new chillers consumed 30-40% less energy. This has resulted in an annual saving of more than 1,000,000 kWh, which is equivalent to a 700-ton reduction in CO2 emissions.

Note: The coefficient of performance (COP) of the old chillers were about 3.5, with relatively high maintenance and operation costs.

Information provided by Towngas

Case Study 2 – Oil-free, VSD, Air-cooled Chillers

In 2014, an oil-free air-cooled chiller was installed at an office building in Kowloon Tong, replacing an old air-cooled chiller of similar capacity.

Compared to the old chiller, electricity consumption of the oil-free chiller is 30% less, resulting in an annual energy saving of more than 65,800 kWh.

With this retrofit, there is an additional annual maintenance cost HKD$20,000 incurred to the building owner with the new chiller installed. However, the retrofit also resulted in a number of benefits in other areas. The oil-free chiller is smaller and lighter than the old chiller, hence there were no issues in regarding the building’s space and structural requirements. Furthermore, saving space adds value to the retrofit work as the space can then be used for other applications. Also, as the oil-free chiller is more silent, there was no need to add silencers or an acoustic enclosure to the chiller. This can save costs if the chiller is installed near residential buildings.

Information provided by Business Environment Council

2.4.9 Variable Speed Drives ("VSD") on Chilled Water Pumps

Source: Southerns Water Technology

Why?

- significant energy savings
- relatively low equipment and maintenance costs

Where do they work best?

Office Buildings (Types 1 & 2)

Hotel Buildings

Overview

Similar to VSD chillers, VSD pumps modulate pump's motor speed based on actual demand, thus saving energy from unnecessarily high pumping powers. There are numerous applications for VSD pumps but they are most commonly used in HVAC plants.

VSD pumps require corresponding control and piping systems to be set up, for example, parallel pumping through multiple pumps to deliver the same flow rate, but at a lower pressure and pump speed to achieve energy savings. These pumps are particularly efficient when coupled with primary flow chiller plants.

In addition, VSD pumps can also be used as a commissioning tool to set a desired pump flow rate instead of traditional resistance-based hydraulic devices that waste energy on unwanted pumping.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

VSD on Chilled Water Pumps

Building Type		Office Type 1		Office Type 2		Hotels	
Scenario		End-of-Life	Total Cost	End-of-Life	Total Cost	End-of-Life	Total Cost
Capital Cost (per m^2 building area)		HK$5	HK$9	HK$5	HK$9	HK$3.4	HK$7
Payback Period (years)		0.4	0.8	0.3	0.7	0.2	0.4
Saving Potentials (per m^2)	Cost	HK$11/year		HK$13/year		HK$17/year	
	Energy	10 kWh/year		12 kWh/year		15 kWh/year	
	Carbon	6 kg CO_2-e/year		7 kg CO_2-e/year		9 kg CO_2-e/year	

Advantages

- technology is mature
- significant energy savings
- relatively low cost
- reduced maintenance costs with reduced pump wear

Limitations

- would need parallel pumping through common headers to maximise the cost savings of VSD pumps
- primary variable flow may cause system instability in certain chiller plants, so building managers are advised to seek input from manufacturers when setting up their control strategies
- may require recommissioning of existing plants
- likely require other upgrades to work, such as a chilled water pipe header arrangement

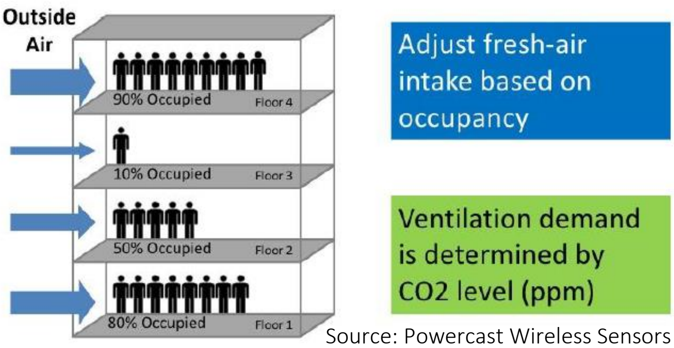
Additional Considerations

- can be upgraded together with chiller plants and building management system (BMS) controls to achieve maximum efficiency
- existing pumps may be able to adopt new VSD controller to achieve similar effects

Relevance to Landlords and Tenants

- landlords are responsible for central chiller plant upgrades
- cost savings from reduced chiller plant energy use are directly financially beneficial to landlords and potentially to tenants in the longer term.

2.4.10 Demand-controlled Ventilation ("DCV")



Source: Powercast Wireless Sensors

Why?

- significant energy savings
- improves indoor air quality

Where does it work best?

Office Buildings (Types 1 & 2)

- general office areas that require fresh air supply

Hotel Buildings

Overview

As the building fabric improves and lighting/computer systems become more efficient, fresh air treatment has become the single largest cooling load in a modern building, so it has potential for significant energy savings.

DCV modulates ventilation rates to suit fresh air demands, so that energy can be saved by avoiding excessive cooling, and in some cases heating and dehumidification, of air supplied to buildings. For example, the number of occupants and fresh air demand can be estimated by CO_2 sensors that are typically located in occupied zones. The CO_2 concentration set-point is typically between 800 and 1000 parts per million (ppm), and the system will automatically adjust outdoor air intake to maintain the CO_2 set-point for optimal performance and meet fresh air demands.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Demand-controlled Ventilation					
Building Type		Office Type 1	Office Type 2	Hotels (Dining, Multifunction and Kitchen)	Hotels (Guestroom fan cycle)
Capital Cost (per m^2 building area)		HK$158	HK$33	HK$4	HK$0.2
Payback Period (years)		3.9	0.6	0.5	0
Saving Potentials (per m^2 building area)	Cost	HK$40/year	HK$58/year	HK$9/year	HK$11/year
	Energy	36 kWh/year	51 kWh/year	8 kWh/year	10 kWh/year
	Carbon	21 kg CO_2-e/year	31 kg CO_2-e/year	5 kg CO_2-e/year	6 kg CO_2-e/year

Advantages

- technology is mature
- significant energy savings
- improves indoor air quality
- reduced usage of belt drive can help extend equipment lifetime due to reduced wear and tear
- buildings with direct fresh air-intake air handling units (AHUs) can adopt DCV easily

Limitations

- higher capital cost if there are a high number of AHUs or fan coil units (FCUs), as air volume dampers and CO_2 sensors will need to be installed
- high capital cost to implement in hotels due to the large number of rooms

Additional Considerations

- DCVs are most efficient in irregularly occupied office areas, e.g. meeting rooms
- apart from using CO_2 sensors, fresh air demand can also be measured by integration with intelligent building systems, e.g. staff card records or CCTV People Counting Systems
- operational and maintenance considerations, e.g. recalibration of ventilation systems and CO_2 sensors
- re-commissioning will generally be required after installing DCVs
- for buildings that are difficult to retrofit controls, or with a large number of rooms, like hotels, cycling (turning off fresh air supply during periods with low occupancy rates) will be a more feasible option

Relevance to Landlords and Tenants

- landlords are primarily responsible for HVAC system upgrades
- cost savings from reduced ventilation energy use are directly financially beneficial to landlords and potentially to tenants in the longer term

2.4.11 Electrically Commutated ("EC") Plug Fans

Source: ebm-papst

Why?

- significant energy savings
- long lifetime with low noise levels

Where do they work best?

Office Buildings (Types 1 & 2)
Hotel Buildings

Overview

Traditional air handling units ("AHUs") and primary air units ("PAUs") rely on a single belt driven centrifugal fan controlled by a variable frequency drive ("VFD") motor. This allows control over fan speeds but the minimum fan power output is still 50% of a fan's rated capacity.

Small brushless EC plug fans, which by themselves are around 5% more efficient than VFD motors, can be installed in an array to form a fan-wall. As multiple fans are used to produce the desired flowrate, individual fans can be shut off in part-load conditions to further reduce air flow, and therefore allowing energy saving levels beyond what VFD motors could do.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

EC Plug Fans							
Building Type		Office Type 1		Office Type 2		Hotels	
Scenario		End-of-Life	Total Cost	End-of-Life	Total Cost	End-of-Life	Total Cost
Capital Cost (per m^2 building area)		HK$84	HK$462	HK$4	HK$22	HK$5	HK$29
Payback Period (years)		9.6	52.6	2.2	11.9	0.3	1.6
Saving Potentials (per m^2 building area)	Cost	HK$9/year		HK$1.9/year		HK$18/year	
	Energy	8 kWh/year		1.6 kWh/year		16 kWh/year	
	Carbon	5 kg CO_2-e/year		1 kg CO_2-e/year		10 kg CO_2-e/year	

Advantages

- technology is mature
- can be easily retrofitted into existing AHUs or PAUs, making plug fans a viable replacement for end-of-life motors
- allow a larger degree of control over the fan speeds to save fan energy usage
- extended lifetime as EC plug fans do not use belt drives in their operation
- greatly reduced noise levels which can improve productivity in adjacent areas

Limitations

- limited choice of suppliers that could be an issue for certain projects

Additional Considerations

- the energy saving performance is highly dependent on the capabilities of control systems and air delivery systems
- existing air handling units can be retrofitted with plug fans

Relevance to Landlords and Tenants

- landlords are responsible for HVAC system upgrades
- cost savings from reduced ventilation energy use are directly financially beneficial to landlords and potentially to tenants in the longer term

2.4.12 Direct Current Fan Coil Units

Source: EuroKlimat

Why?

- significant energy savings
- long lifetime with low noise levels

Where do they work best?

Office Buildings (Type 2)

- general office areas that require fresh air supply

Hotel Buildings

- guest rooms
- back-of-house (BOH) offices

Overview

Direct Current ("DC") Fan Coil Units ("FCUs") use DC motors instead of traditional alternating current ("AC") motors. DC FCUs save energy not only by using a more efficient motor, but also by their ability to modulate air supply rates according to local zone cooling demands.

In traditional AC motors, fan speed does not have much impact on fan power consumption. In contrast, DC FCUs are very sensitive: a slight reduction in fan speed can result in significant fan power savings. Two-third of the energy used in fans can be saved with appropriate FCU controls.

DC FCUs are also a lot quieter and have longer lifetimes comparing to AC FCUs due to less vibration and heat. As to enhancing comfort, it is worth noting that when DC FCUs were first available in the market, they were mainly used in premium hotel bedrooms.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Direct Current Fan Coil Units

Building Type	Office Type 2		Hotel	
Scenario	End-of-Life	Total Cost	End-of-Life	Total Cost
Capital Cost (per m^2 building area)	HK$84	HK$153	HK$98	HK$134
Payback Period (years)	5.0	9.2	4.5	5.5
Cost	HK$17/year		HK$24/year	

Saving Potentials (per m² building area)	Energy	15 kWh/year	22 kWh/year
	Carbon	9 kg CO_2-e/year	13 CO_2-e/year

Advantages

- technology is mature
- significant energy savings
- extended lifetime as DC FCUs do not use belt drives in their operation
- reduced noise levels

Limitations

- higher capital costs than their AC counterparts
- require additional wiring for controls

Additional Considerations

- retrofitting existing FCUs to DC motors is now available in the market to reduce costs
- suitable for areas where noise levels need to be low

Relevance to Landlords and Tenants

- landlords are primarily responsible for HVAC system upgrades
- cost savings from reduced ventilation energy use are directly financially beneficial to landlords and potentially to tenants in the longer term. Tenants benefit from reduced noise levels

Case Study – Fan Coil Unit

A In 2012, a hotel of 274 guest rooms in Sheung Wan installed a variable speed intelligent fan coil unit in each room during the construction phase of the new hotel building. Each fan coil unit consists of a permanent magnet, brushless, direct current motor, and comes with a corresponding control box and thermostat control system with return air duct temperature sensor.

The motor with permanent magnet is more energy efficient than the conventional fan coil units with alternating current motor. The thermostat system regulates fan speed automatically according to room temperature against the temperature set point. In addition, the thermostat system has a "quick cool" function, in which the motors operate at 5% above regular high speed capacity to achieve the desired room temperature quickly, then automatically lower the motor speed upon reaching the temperature set point.

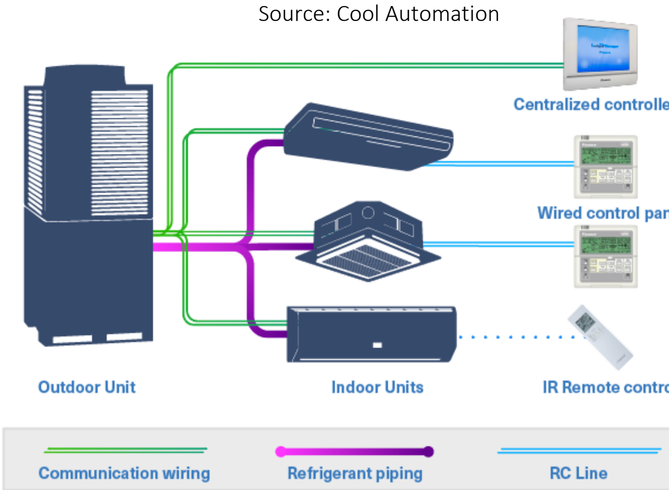
Compared to the conventional fan coil units, the new units reduced energy consumption by 40% when operating at high speed, 66% when operating at medium speed, and 80% at low speed. On average, the energy consumption was reduced by 76%.

Additionally, the waste heat generated by the fan coil units were reduced as well. The operating temperature increase was reduced by 58% when operating at high speed, 87% at medium speed, and 95% at low speed. With the fan coil units operating 24 hours a day and with each unit operating at an average of 600 cubic feet per minute, the fan coil units allowed the hotel to save a total of 149,433 kWh of electricity per year. The resultant monetary savings are approximately HKD$194,263 per year, translating to a 2.12-year payback period.

Information provided by REC Engineering and Holiday Inn Express Hong Kong SoHo

2.4.13 Variable Refrigerant Flow for High Efficiency Direct Expansion

Source: Cool Automation



Why?

- significant energy savings
- simple installation
- allows individual zone control while using a direct expansion system

Where does it work best?

Office Buildings (Type 3)

- office areas
- areas that need air-conditioning day-and-night

Hotel Buildings

- areas that may not have access to chilled water

Overview

Variable Refrigerant Flow ("VRF") air conditioners typically consist of multiple indoor expansion units, which absorb heat, connected with an outdoor condensation unit that releases heat to the environment.

Traditional direct expansion ("DX") systems are relatively low cost and energy efficient for small installations; they require simple installation and less ductwork comparing to chiller water/air systems. VRF systems not only reside on DX technology, but can also provide solutions to the limitations of older DX systems. For instance, a compressor in conventional multi-split DX system must be turned on or off completely in response to a master controller, while a VRF system can adjust the flow of refrigerant to each indoor evaporator unit separately[8] through a variable speed drive-driven compressor, allowing VRF systems to be very efficient especially in part-load conditions.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Variable Refrigerant Flow (for Office Type 3 only)			
Scenario		End-of-Life	Total Cost
Capital Cost (per m^2 building area)		HK$51	HK$254
Payback Period (years)		1.3	6.4
Saving Potentials (per m^2 building area)	Cost	HK$40/year	
	Energy	35 kWh/year	
	Carbon	21 kg CO_2-e/year	

Advantages

[8] http://www.seedengr.com/Variable%20Refrigerant%20Flow%20Systems.pdf

- technology is mature
- can provide heating or cooling depending on the installed system
- tackles some of the limitations of traditional DX systems, such as lack of zone control and short lifetime

Limitations

- higher capital cost than traditional DX systems
- pipework replacement will normally require draining and re-filling the entire circuit with refrigerant
- VRF systems have minimum size requirements
- they also have shorter lifetime than chiller water systems

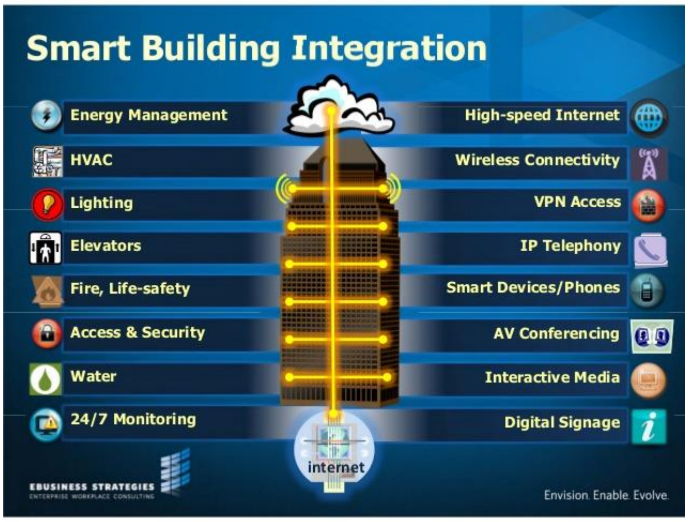
Additional Considerations

- VRF systems will be very efficient in areas that require both cooling and heating
- generally used when no centralised cooling systems are present (i.e. Type 3 Office)

Relevance to Landlords and Tenants

- both replacement costs and cost savings will primarily be on the tenant-side

2.4.14 Intelligent Building Control Systems



Source: Ebusiness Strategies

Why?

- effective for large chiller plants
- some buildings may already have existing building management systems

Where do they work best?

Office Buildings (Types 1 & 2)

- central chiller plant
- energy management for the entire building

Hotel Buildings

- guestroom management
- central chiller plants
- energy management for the entire building

Overview

Building management systems ("BMSs") are fairly common in buildings, but are often treated simply as on/off control devices. Smart building controls collect building information and optimise building equipment for energy efficiency. They can be applied to various equipment, including but not limited to chiller plants and lighting systems (see the case studies below).

For instance, a chiller plant optimiser for improving chiller plant controls will calculate the best combination of chiller staging control, temperature set-point, number of pumps and cooling towers based on real-time cooling load, outdoor air temperature and humidity. The module can also calculate the time required to pre-cool the building in early morning based on weather conditions and previous operational data.

For hotels, an example of this can be an intelligent bedroom management system: if the hotel's default temperature is 22°C, the system will set an unrented room's set-point to 26°C and turn off all lighting and AV systems. The room air-conditioning will only be turned on again if the temperature exceeds 26°C. If the room is rented but not occupied, the system will change the set-point to 24°C, or any other temperature at the building manager's discretion.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Smart Controls for Chiller Plants				
Building Type		Office Type 1	Office Type 2	Hotel
Capital Cost (per m^2 building area)		100*	100*	38*
Payback Period (years)		10.5	8	3.0
Saving Potentials (per m^2 building area)	Cost	10 HK$/year	13 HK$/year	12 HK$/year
	Energy	8 kWh/year	11 kWh/year	11 kWh/year
	Carbon	5 kg CO_2-e/year	7 kg CO_2-e/year	7 kg CO_2-e/year

*Cost figures are less sensitive to building area changes than other options; figures above are for the sample studies

Advantages

- can have significant energy savings for large chiller plants
- buildings may already have BMSs with certain smart control features

Limitations

- initial costs can be high
- annual license fees may apply to smart control systems
- limited usefulness for buildings without central chiller plants

Additional Considerations

- since BMSs are typically not utilised to their full extent, building operators are recommended to explore control features offered by the existing systems before looking at an upgrade

- these systems also collect useful operational data that can be logged onto an energy management platform, and utilised to look for additional energy saving opportunities via data analytics tools

Applicability to Landlords/Tenants

- all upgrades in centralised operations are generally paid for by landlords and, in turn, primarily benefit landlords financially, however tenants should benefit in terms of comfort and potentially in the longer term as to costs

Case Study – Smart Lighting Controls

An office within a building in Tsim Sha Tsui installed smart lighting control system into their office in 2016.

The lighting control system is a cloud-based system that controls each light fixture individually. Through the cloud server, the user can assign instructions to the light fixtures, helping to optimise lighting use by spatial and time variations. Occupants can also use a mobile application to control the lights of the office. The system enabled automatic lighting on/off schedule and personalised granular control, so lights were only turned on where and when they are needed. The system was installed to control approximately 100 4-feet T5 tubes at the office.

Retrofitting this technology involves connecting a controller at each light fixture, and it takes approximately 5 minutes for each fixture controller installation.

Prior to installing this system, unoccupied areas were often illuminated even with one-third of the staff frequently working outside of the office. The installation of this system reduced daily energy cost by 53%.

The retrofitting of this technology can help achieve the largest energy savings in spaces with dynamic lighting usage, such as offices with low occupancy rates and non-desk bound staff. On the other hand, opportunities for energy savings would be less in areas with relatively static lighting usage patterns, such as lobbies or warehouses.

Information provided by En-trak

Case Study 2 – Chiller Optimization

In 2015, the installation of a chiller plant control programme was completed in an office complex in Wan Chai, with the system controlling 6 water cooled centrifugal chillers, some of which are variable speed drive and some are constant speed drive. The programme features automatic control of the chiller operation, integrated control of start-stop sequence, and integrated control of chilled water supply temperature reset – all of which were manually controlled by the operator prior to the upgrade.

The start-stop sequence of the chillers are optimised in that during start up, VSD chillers are started first followed by CSD chillers, and during the shut-down process, CSD chillers are stopped first followed by stopping VSD chillers. This automated control helps to reduce energy consumption during start-stop in the mornings and evenings. The automatic chilled water supply temperature reset allows chilled water supply temperature to be adjusted more frequently to match the actual cooling load demand of the building. Overall, these optimization strategies approximately reduced the electricity consumption of chiller plant by 16%.

Information provided by SHKP and its property management subsidiaries

Case Study 3 – Smart Controls for HVAC Systems

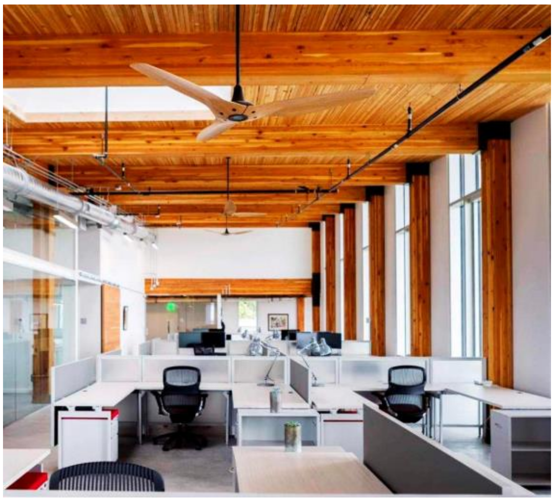
In 2012, a smart control system for HVAC system was applied to a hotel of 274 guest rooms in Sheung Wan. The smart control system provides automated, real-time optimization of the energy consumption performance of HVAC system according to building load and local weather conditions through continuous monitoring and subsequent fine tuning of system operations. The application of the smart control system involves applying a software package of control algorithms to the equipment of HVAC system, and linking up with the existing building management system. Accordingly, the prerequisite to the applying this smart control system is a chiller with high-level interface, and a high-level interface with open protocol-type building management system.

Applying the smart controls for HVAC system in the hotel in Sheung Wan required putting in place additional sensors and an additional computer. The total initial cost of installing the smart control system was HKD$498,000. The smart control system reduced the energy consumption of the HVAC system by 27%, which translated to a 16.2% saving of the entire building's energy consumption. The payback period of the energy optimization solution was 1.43 years. The energy savings were achieved while maintaining the same level of thermal comfort in the hotel.

The energy saving achieved from this smart control systems is dependent on the scale of the HVAC system and the length of the HVAC system's operating time.

Information provided by REC Engineering and Holiday Inn Express Hong Kong SoHo

2.4.15 High Volume Low Speed ("HVLS") Fans



Source: Big Ass Fans

Why?

- Simple installation
- Improved thermal comfort

Where do they work best?

Office Buildings (Types 1, 2 & 3)

- lobby, circulation and communal areas
- open plan office areas

Hotel Buildings

- guestrooms, lobby, circulation and communal areas
- naturally ventilated areas

Overview

High-volume low-speed (HVLS) fans are mechanical fans with a large diameter rotating in low speed. Although HVLS fans do not directly reduce the room temperature, they produce a cooling effect by increasing air movement thus enhancing evaporation which cools the human body. As the overall air movement is more dependent on the diameter of a fan instead of its rotational speed, HVLS fans will create a larger cooling effect than small high-speed fans[9]. With HSLV fans,

[9] http://www.wisconsinpublicservice.com/business/pdf/efficient_equipment_uwstudy.pdf

it is possible to increase the thermal set points for the space by approximately 2.2°C[10], or even 2.8 – 3.3°C[11], without compromising thermal comfort.

Another example is to use it in circulation areas, such as lobbies, in conjunction with natural ventilation for mixed mode ventilation. This would eliminate the need for air-conditioning for up to 6 – 8 months in a year. HVLS fans are also common in resorts and holiday hotels in places like Singapore. They are installed in hotel lobbies, bedrooms and semi-open areas.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

HVLS Fan					
Building Type		Office Type 1	Office Type 2	Office Type 3	Hotel
Capital Cost (per m^2 building area)		218	218	218	5
Payback Period (years)		10.6	11.5	23.8	11.1
Saving Potentials (per m^2 building area)	Cost (HK$/year)	20	19	9	0.5
	Energy (kWh/year)	18	17	8	0.4
	Carbon (kg CO_2-e/year)	11	10	5	0.24

Advantages

- improve thermal comfort for occupants
- energy can be saved through reduced air conditioning use
- they produce less turbulent air flow, resulting in less disturbance for an office environment
- work well with buildings with access to natural ventilation
- low maintenance requirements
- relatively simple installation

Limitations

- they work best in spaces that have high or open (exposed) ceilings

Additional Considerations

- noise can be a concern, and quieter fans will typically be more expensive
- there are ideal installation heights that should be considered
- larger fans are more effective than smaller fans
- smaller fans can be used in offices, however head height should be considered for safety – generally fans should be installed at least 3m from the ground

[10] http://www.nrel.gov/docs/fy01osti/29513.pdf
[11] http://shho.myweb.usf.edu/PUB/ApplThermEng2009a.pdf

Relevance to Landlords and Tenants

- generally, reduction in cooling energy in tenant spaces will result in cost savings for the landlord, as tenants simply pay a fixed charge that covers cooling amongst other things
- therefore this technology will be directly beneficial to the landlord in terms of costs, unless tenant pays for actual cooling (as assumed in Type 3 offices), but in the longer term tenants may benefit financially

Case Study – High Volume Low Speed Fans

The Zero Carbon Building in Kowloon Bay was built in 2012 with a total of 15 high volume low speed ceiling fans installed: 10 eight-bladed fans with gearless direct-drive motors with diameters of 95 inches, 3 three-bladed fans spanning 52 inches, 1 three-bladed fan spanning 60 inches, and 1 eight-bladed fan with a gearbox with a diameter of 95 inches. 3 fans are located in the office and operates in conjunction with chilled beams and underfloor displacement cooling to cool the area. The other fans operate with the underfloor displacement cooling system to cool the remaining areas of the building, including exhibition areas and a multipurpose hall. The fans are in operation throughout most of the year.

The fans have airfoil and winglet designs for efficient airflow by eliminating vortex formation at airfoil tips. The increased airflow enhances evaporation rates for comfort and reduces perceived temperature by around 2 degrees Celsius. The fans further improve ventilation and distribution of conditioned air, reducing the demand for air conditioning.

It is estimated that the high volume low speed fans reduce the building's cooling energy consumption by 14%, compared to solely relying on the other components of the building's cooling system to achieve the same cooling effect.

Information provided by CIC - Zero Carbon Building, Big Ass Fans

2.4.16 Carbon Monoxide ("CO") Sensors in Carpark Fans

Why?

- short payback period
- easy to retrofit in an existing system

Where do they work best?

Office Buildings (Types 1, 2 & 3)
Hotel Buildings

Source: Cool Automation

Overview

Air pollutant levels in carparks typically peak at morning, lunch and after-work hours. However, carpark extraction fans often run continuously or on fixed schedules to maintain safe CO levels. Installing CO monitors and controls can provide a demand-based operation to switch off or slow down the fans during non-peak periods. VSD controllers can also be added to existing fans to improve energy performances in low-demand scenarios.

CO sensors can not only reduce electricity consumption, but also extend the lifetime of the fans.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Carpark CO Sensors		
Capital Cost (per m^2 carpark area)		HK$90
Payback Period (years)		1.4
Saving Potentials (per m^2 carpark area)	Cost	HK$66/year
	Energy	59 kWh/year
	Carbon	35 kg CO_2-e/year

Advantages

- short payback period
- mature and reliable technology, so sensors can be easily retrofitted into existing systems
- significant energy savings can be achieved, depending on size and operation of the carpark
- reduced fan use, which increases fan lifetime and reduces maintenance costs

Limitations

- calibration and maintenance work will be required for optimal performance

Additional Considerations

- carpark air quality standards need to be monitored to ensure a safe operation and fulfil Transport Department requirements
- need to ensure that the smoke extraction system will not be affected

Relevance to Landlords and Tenants

- both installation costs and cost savings will be on the landlord-side

2.4.17 Variable Voltage Variable Frequency ("VVVF") Lift Drives

Source: ebm-papst

Why?

- significant energy savings
- enhanced equipment lifetime

Where do they work best?

Office Buildings (Types 1, 2 & 3)
Hotel Buildings
(also residential buildings or any other high-rise buildings)

Overview

VVVF lift drives are able to regulate both voltage and frequency inputs to the motor throughout the journey via a frequency inverter. This allows VVVF lifts to use much less electric current and energy during acceleration and deceleration, and reduces the wear and tear of the equipment during the start or stop phase of the motor[12].

These lifts can be used in various types of multi-storey buildings for energy and cost savings.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

VVVF Lift Drives			
Scenario Type		End-of-Life	Total Cost
Capital Cost (per m^2 building area)		HK$0	HK$375
Payback Period (years)		0	92
Saving Potentials (per m^2 building area)	Cost	HK$4/year	
	Energy	4 kWh/year	
	Carbon	2 kg CO_2-e/year	

Advantages

- technology is mature
- moderate to significant energy savings depending on building height
- extended equipment lifetime, improved safety, speed, reliability and riding comfort
- they are becoming a norm for new lift installations

Limitations

- high retrofitting costs which make this very expensive unless a new lift system is needed – this is why the figures above are based on the incremental cost of VVVF lifts compared with a like for like replacement at end of life

[12] http://ee.emsd.gov.hk/english/lift/lift_tech/lift_tech.html

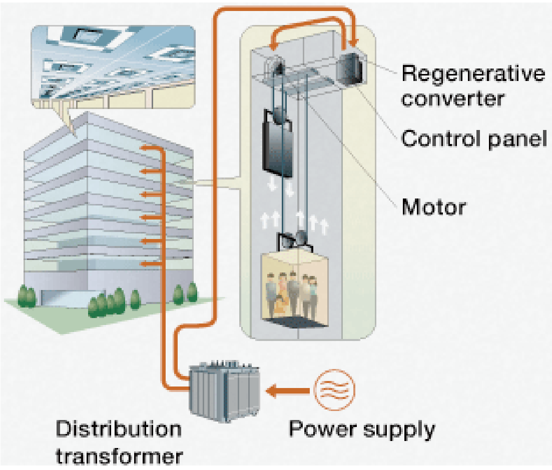
Additional Considerations

- amount of energy saved depends on the load of the lift
- can be combined with regenerative braking drives (see Section 2.4.18 below) for maximum energy efficiency

Relevance to Landlords and Tenants

- cost savings primarily for landlords, with potential savings for tenants in the longer run

2.4.18 Regenerative Braking Lifts



Source: Mitsubishi Electric

Why?

- able to harness energy that would otherwise be dissipated as heat
- energy savings in air conditioning

Where do they work best?

Office Buildings (Types 1, 2 & 3)
Hotel Buildings
(also residential buildings or any other high-rise buildings)

Overview

In conventional lifts, the power generated by traction is dissipated as heat in the building, whereas lifts with a regenerative function are able to use their motors as a generator when the carriage is travelling down, and feed the current back into the facility's electrical grid for usage in elsewhere. When the lift car is travelling up with a light load, or down with a heavy load, the system can generate more power than it uses. Over time, the power generated can add up to noticeable savings.

The amount of regenerative power produced depends on several factors, including building height, operating speed, elevator capacity and type/age of the lift.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Regenerative Braking Lifts			
Scenario Type		End-of-Life	Total Cost
Capital Cost (per m² building area)		HK$13	HK$390
Payback Period (years)		3.1	95
Saving Potentials (per m² building area)	Cost	HK$4/year	
	Energy	4 kWh/year	
	Carbon	2 kg CO_2-e/year	

Advantages

- technology is mature
- improved safety, speed, reliability and riding comfort
- energy savings in both lift and air-conditioning use, by being able to generate electricity and reduce heat dissipation at the same time
- surplus energy can be used by other electrical systems[13]

Limitations

- high retrofitting costs which make this very expensive unless a new lift system is needed, which is why the figures above are based on the incremental cost of regenerative braking lifts compared with a like for like replacement at end of life
- actual energy savings are dependent on lift usage and building height

Additional Considerations

- they work best and save more energy in high-rise buildings with multiple lifts
- there are also some add-on regenerative braking modules available in the market

Relevance to Landlords and Tenants

- cost savings primarily for landlords, with potential savings for tenants in the longer run

2.4.19 Heat Pumps

Source: which.co.uk

Why?

- relatively short payback period
- long lifetime with low noise levels

Where do they work best?

Hotel Buildings

- domestic how water system pre-heat or as the primary heat source

Overview

Heat pumps extract heat from the environment to heat up water for domestic or plant use. Common sources of heat include ambient air and waste heated water. As a replacement of electrical resistance heaters, heat pumps can generate the same amount of hot water with half or even one-third of the electrical energy and greatly reduce operational costs.

[13] https://www.emsd.gov.hk/filemanager/en/content_764/applctn_lift_rgnrt_pwr.pdf

Heat pumps out-perform gas-fired water heaters in terms of reduced carbon emissions with similar operating costs. They also complement water-cooled chillers extremely well, as the hot water leaving the chiller plant as waste heat can be used as the heat source for hot water systems.

They work most efficiently as a pre-heating system that brings incoming water to about 40 – 45 °C before further heating by a secondary system. There are also water source heat pumps that work in a similar way but not modelled in this Guide.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Heat Pumps in Hotels		
Capital Cost (per m^2 building area)		HK$74
Payback Period (years)		5
Saving Potentials (per m^2 building area)	Cost	HK$15/year
	Energy	13 kWh/year
	Carbon	8 kg CO_2-e/year

Advantages

- technology is mature
- highly efficient with a 3 – 3.5 coefficient of performance (COP) generally
- relatively short payback period
- can be used as a backup cooling system in summer

Limitations

- noise control may be required for air source heat pump
- air source compressor will require more maintenance needed comparing to water source heat pumps
- additional spaces needed for outdoor units
- COP will decrease in cold winters

Additional Considerations

- buildings can also consider water source heat pumps that make use of waste heat generated from centralised chiller plants
- further considerations when installing water source heat pumps to recover waste heat from the central chiller plant include:
  - additional space required in the central chiller plant to install piping and valves
  - distance from the chiller plant to heat pump room
  - piping route from chiller plant room to the hot water system – including the heat pump room

Relevance to Landlords and Tenants

- office buildings rarely need hot water systems
- all energy savings will be gained by hotel owners

2.4.20 Solar Water Heating ("SWH") Systems

Source: Duda

Why?

- highly cost-effective (if in the right location)
- reduced water heating load for gas/electric heaters

Where do they work best?

Office Buildings (Types 1, 2 & 3)

- only for areas that need space/water heating

Hotel Buildings

- hot water for guestrooms

Overview

Solar water heating systems can be effectively used to preheat water for space heating or hot water supply, by absorbing heat in solar radiation through solar collectors. In general, there are 2 types of SWH systems: vacuum tube type or panel type. These are typically installed on unshaded roofs and tilted 21.5 degrees toward South to maximise exposure to solar energy. SWH systems typically have a 60-70% efficiency and will normally work well as a pre-heating system, or with heat pumps and gas-fired boilers.

Hotels have significant hot water demand from the guests, making them a good candidate for SHW panels. Some office buildings may also have showering facilities, but their small hot water demands can typically be met by local electric heaters.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Solar Hot Water Heating		
Capital Cost (per m^2 of panel)		HK$4,000
Payback Period (years)		4.5
Saving Potentials (per m^2 of panel area)	Cost	HK$900
	Energy	800 kWh/year
	Carbon	475 kg CO_2-e/year

Advantages

- technology is mature

- one of the most cost-effective renewable technology in Hong Kong for buildings that have hot water demand

Limitations

- need unshaded rooftop space for maximum efficiency
- for a commercial-scale system, additional water tanks or pumps may be needed
- mounting frames for the system are also a major part of capital costs

Additional Considerations

- maintenance access and regular cleaning required for efficient operations
- landlord may wish to consider the best means of utilization of limited rooftop space – solar hot water panels or solar PV panels once the feed-in tariff is in place (expected to come into place in 2018 pursuant to the Scheme of Control Agreements)

Relevance to Landlords and Tenants

- office buildings rarely need hot water systems
- energy savings from water heating will benefit hotel owners

Case Study – Solar Hot Water

A hotel with 36 floors and 274 guest rooms in Sheung Wan was built in 2012, with a solar hot water system built-in.

The system includes a metal frame built on the hotel roof, supporting 24 vacuum-type solar hot water panels with a total net surface area of 72 square meters. The solar hot water panels are inclined at 23.5 degrees facing south. The solar hot water panels capture solar radiation and transfer thermal energy to heat up a closed-loop circulation of water. On an average day, the system can heat water up to 60 degrees Celsius, and can reach up to 70 degrees Celsius plus in summer. The water is finally transferred through heat exchangers, where the thermal energy is used to heat water as part of the hot water generation process. A small amount of energy input is required for water recirculation pumping.

1.32% of the hotel's total energy consumption is satisfied by the solar hot water system, saving 70,000 kWh of electricity per year.

Prior to installing the system, the hotel carried out a study and concluded that it was unlikely that there will be new, tall structures in the area that may block sunlight from the solar hot water panels. Another key consideration was to ensure the panel-supporting frame was strong enough to withstand severe weather conditions yet was not overwhelmingly heavy.

Information provided by REC Engineering and Holiday Inn Express Hong Kong SoHo

2.4.21 Solar Pool Heating


Source: Green Future

Why?

- reduces pool water heating load
- relatively short payback period

Where does it work best?

Hotel Buildings

- swimming pools

Overview

Similar to Solar Water Heating systems mentioned above, Solar Pool Heating relies on pumping pool water through solar collectors, where solar radiation is absorbed to heat up the water, and the heated pool water will return back into the pool.

This system pre-heats pool water and reduces the amount of energy needed for water heating.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Solar Pool Heating		
Capital Cost (per m^2 of panel)		HK$3,900
Payback Period (years)		8.8
Saving Potentials (per m^2 of panel area)	Cost	HK$450
	Energy	400 kWh/year
	Carbon	240 kg CO_2-e/year

Advantages

- works well with heat pump pre-heating systems
- payback period is relatively short

Limitations

- heating output will drop on cold and cloudy days
- needs unshaded rooftops for better efficiency
- may need additional water tanks to store pre-heated water
- mounting frames for the system are a major part of capital cost

Additional Considerations

- can act as a supplementary system to the existing heating system or heat pump, and part of the water can also be pre-heated by waste heat (e.g. from chiller plants)
- maintenance access and regular cleaning required for efficient operations

Relevance to Landlords and Tenants

- office buildings rarely need hot water systems
- energy savings from water heating will benefit hotel owners

2.4.22 Photovoltaic ("PV") Panels

Source: EMSD HK RE Land

Why?

- by 2018/19, the feed-in-tariff will enable buildings owners to feed energy into the grid at a premium above the retail price
- can directly offset your electricity consumption

Where do they work best?

Office Buildings (Types 1, 2 & 3)
Hotel Buildings
Especially buildings with large exposed and unshaded rooftops.

Overview

Solar PV is currently the most popular choice of renewable energy when the building has no or limited heating/hot water demand. Solar PV panels convert solar energy into electricity. Their technology is advancing and the typical efficiency is about 15-20%, with a maximum efficiency around 25% as of 2017.

The output of PV is sensitive to weather conditions. Their efficiency drop significantly if they are shaded or not tilted according to solar elevation angles. In Hong Kong, the optimum installation position is on an unshaded roof top, tiled 21.5° toward south. There are also various types of window-based solar PV systems emerging in the market.

Modelled Costs and Saving Potentials (assumptions are listed in Appendix A)

Rooftop PV System		
Capital Cost (per m^2 of panel)		HK$9000
Payback Period (years)		34.6
Saving Potentials (per m^2 of panel)	Cost	HK$260
	Energy	230 kWh/year
	Carbon	138 kg CO_2-e/year

Advantages

- directly offset electricity consumption
- power generation increases when cooling demand increases, as electricity output is directly related to amount of solar radiation received

- mature technology with a wide range of panels readily available in the market

Limitations

- relatively high capital costs that result in a long payback period
- require unshaded rooftop area for maximum efficiency
- battery and controls will take up space and increase capital cost

Additional Considerations

- the system will need to have a minimum scale to be efficient enough for operation
- glare reflected from PV panels may sometimes create nuisance to adjacent buildings
- maintenance required to keep the surface of solar panels clean for maximised generation
- access to rooftop panel needs to be planned
- panel supporting frames are also a major part of the cost, but systems are developing rapidly and costs coming down with some virtually frame-free technologies coming onto the market
- feed-in tariffs from power companies will be introduced in 2018 as set out in the new Scheme of Control Agreements ("SCA")[14] to incentivise and shorten the payback period for PV panels

Relevance to Landlords and Tenants

- electricity generated from rooftop PV panels will generally be beneficial to landlords as they have control of rooftops.

[14] http://www.enb.gov.hk/en/resources_publications/agreement/

The energy saving technologies and initiatives below are not modelled with costs and energy savings due to their case-to-case variability. We included brief descriptions below for you to consider them as potential options.

2.4.23 Retro-commissioning ("RCx")

Retro-commissioning ("RCx") is a systematic and continual process to evaluate an existing building's performance, identify opportunities for operational improvements, and bring the building stock up to defined performance standard. This process aims to fully utilise opportunities, methods and adjustments to improve existing building equipment and systems for better energy performance, often without incurring any capital costs.

A typical RCx routine includes i) collecting building usage and equipment data; ii) analysing data to check whether equipment and systems are functioning properly to meet design or users' requirements; iii) fine-tuning of building equipment and control systems for improved energy performance; and iv) periodic monitoring and verification of equipment and systems.

The underlying premise is that most buildings lose up to 30% of their efficiency in the first three years of operation[15]. This can be due to changes induced by addition, alteration and improvement works performed in the building, drift off from control set points, reduced accuracy or sensitivity of sensors, or substandard maintenance.

RCx can involve actions such as calibrating control sensors, adjusting timers and clocks, optimizing control sequences, adjusting lighting level, reviewing control programmes to suit operations, and more.

On average RCx can reduce a building's energy consumption by between 7-22%, with actual energy savings highly dependent on the building's original existing conditions. More information about RCx and RCx case studies can be found in EMSD's *Technical Guidelines on Retro-commissioning*[16].

Advantages

- little to no cost depending on the scale of work, thus the payback period will be short
- prolongs equipment life and reduces the chance of equipment or system failure
- enhances documentation of buildings' data

Considerations

- energy and cost savings will be dependent on building conditions
- RCx is a continuous process, so building equipment and controls need to be monitored, checked and adjusted regularly to ensure their optimal energy performances

[15] http://ashraeny.org/images/meeting/102516/buildingeq_ase_ _ny_chapter.pdf
[16] https://www.emsd.gov.hk/filemanager/en/content_718/2017%20TG-RCx.pdf

2.4.24 High Efficiency Gas-fired Cooking Appliances

Source: The Hong Kong and China Gas Company

Cooking appliances, in general, waste considerable amounts of energy as they are often not well-insulated or enclosed, and will lose heat to the surrounding environment. For example, a pot on an open stove only uses 20% of the energy in the gas being burned[17]. Therefore, the key to increasing energy efficiency is to retain the heat inside the appliance and reduce the energy wastage via heat recovery technologies.

For instance, a high efficiency gas steamer[18], with a double water tank design that makes use of a heat exchanger, reuses waste heat from steam generation to preheat water, so less energy is needed to boil water. In a particular case, compared to the traditional steamer, the new steamer reduced exhaust gas temperature by 50%, decreased indoor temperature by 2°C and produced less noise[19]. It also consumed 20% to 30% less energy, translating to HKD$20,000 savings per month and costs similar to a traditional steamer[20].

Furthermore, gas steamers/hot water supply has higher energy end-use efficiency than their electric counterparts from a lifecycle perspective (production, transmission and appliance usage)[21] and they have lower carbon emissions as the towngas feedstock is from naphtha, natural gas and landfill gas.

[17] http://www.grems.hk/Download/Technical%20Guidebook.pdf
[18] http://newscentre.towngas.com/Eng/Cust/Business/CommerceIndustry/images/tg_com_promotion_steamer.jpg
[19] http://newscentre.towngas.com/Eng/Cust/Business/CommerceIndustry/pdf/ChinaHouseCaseSheet.pdf
[20] http://newscentre.towngas.com/Eng/Cust/Business/CommerceIndustry/images/Apple_9Sep_FINAL.jpg
[21] http://www.towngas.com/en/Social-Responsibility/Environmental-Protection/Clean-Production

2.4.25 Radiant Chilled Ceiling Systems (Chilled Beams)

Source: Stylepark Plafotherm® heated and chilled ceiling

The Radiant Ceiling Cooling system is a water-based cooling system that uses ceiling cooling panels to absorb heat in the forms of radiation and convection, and a chilled water pipe system to transfer the heat out. The chilled water pipes are laid behind false ceiling panels. Such a system separates cooling from the ventilation system and allows additional adjustments to improve indoor air quality, for instance, control fresh air intake and pump flow according to actual demands.

In hot and humid climates, a separate air intake system can be installed to dehumidify indoor air and to avoid water vapour condensation on chilled water pipes.

Case Study – Chilled Beams

An office building on Lantau Island near the Hong Kong International Airport had a chilled beam cooling system (system) installed in part of the building in 2011. This was in an area of 850 m^2 hosting nearly 60 staff. With the success of the initial phase of the retrofit, the chilled ceiling has since been expanded to an area of 1200 m2.

The chilled beam cooling system consists of a centralised system which includes a primary air handling unit to dry and pre-cool fresh air, a heat exchanger to raise the chilled water temperature, a set of secondary pump system to supply chilled water, and a set of smart central control system. Local systems include zoned chilled water valves, fresh air control dampers, and chilled ceiling panels.

With the chilled beam cooling system, chilled water temperature can be set higher, at 10 – 15˚C compared to 5 – 7˚C in a fan coil unit system. Since there are no fan coil units, no energy is needed to power the fans and no waste heat is generated from fan motors. Furthermore, fresh air intake and pump flow can then be determined according to actual demand. This retrofit has resulted in an energy saving of more than 40%, compared to the previous conventional fan coil unit system.

Beyond saving energy, other benefits were also observed as a result of the retrofit. The office background noise level was reduced from 54.9 dB to 38.5 dB; the reduced space requirement compared to fan coil unit systems allows for a higher ceiling height; there is a 90% reduction in time needed for routine maintenance of the cooling system as there is no need to clean false ceiling air ducts, and the system parameters of the system can be remote-controlled by maintenance staff through mobile devices; and indoor air quality was improved.

Information provided by Swire Pacific, HAECO

2.4.26 Resizing Plumbing and Drainage Pumps

Pumps are a relatively cheap type of equipment but they consume significant amounts of energy. It is not uncommon for buildings to install oversized pumps that exceed the actual need of the building.

For instance, a building may have a pump to transport domestic water from ground up to a water tank on the rooftop. These pumps typically operate for 2 hours a day to pump an entire day's usage worth of water to the tank. Since pumping energy is directly related to the pumping height and flow rate, a pump can be sized to have a much smaller flowrate but operate longer hours to reduce pumping energy.

Another common example is chilled water pumps in chiller systems. They are also often oversized, so reducing pump size can save significant amounts of energy.

2.4.27 Task Lighting

Source: Contract Office Reps Southern California

Task lighting ensures sufficient light levels on targeted working surfaces by illuminating directly over the specific areas. In addition, users can optimise lighting levels and angles according to their own needs. This helps user focus and perform tasks like reading and writing better, and will reduce eyestrain.

With task lighting in place, the overhead (ambience) lighting power can be decreased while keeping the same, if not higher, levels of productivity. This can be used in conjunction with "Reduced Illuminance to 300 lux" mentioned in Section 2.4.4.

2.4.28 District Cooling System

A district cooling system ("DCS") works in a similar way to centralised cooling systems in buildings, but at a much larger scale. A central chiller plant supplies chilled water (or other media) to multiple buildings through underground pipe networks. Buildings and individual users do not need to install chiller plants as they purchase chilled water from the DCS operator. As a result of not installing chiller plants in buildings, the space saved can be redesigned for other purposes, for example, recreational facilities or sky gardens[22].

The DCS at Kai Tak takes advantage of economies of scale as well as lower seawater temperatures. It is estimated that it will ultimately consume 35% less electricity compared to traditional air-cooled AC systems and 20% less electricity compared to water-cooled AC systems[23]. A DCS plant can also be designed to supply hot water to form a District Heating and Cooling System for areas that require hot water or heating systems. As a result of not installing chiller plants in buildings, the space saved can be redesigned for other purposes, for example, recreational facilities or sky gardens[24].

22 http://www.energyland.emsd.gov.hk/en/building/district_cooling_sys/dcs_benefits.html
23 http://www.energyland.emsd.gov.hk/en/building/district_cooling_sys/dcs.html
24 http://www.energyland.emsd.gov.hk/en/building/district_cooling_sys/dcs_benefits.html

Case Study – Kai Tak District Cooling System

Construction works for the district cooling system at Kai Tak commenced in 2011, with the construction of two plant rooms, a seawater pump room and installation of some chiller equipment, and laying of partial seawater pipes and chilled water pipes. The district cooling system began operation in early 2013. It currently provides chilled water to the Kai Tak Cruise Terminal, a shopping centre, a government office building, EMSD headquarter, Children Hospital and two schools. The remaining construction works are expected to be built in phases to be in line with scheduled development of the Kai Tak Development. Ultimately around 40 kilometres of underground pipes will be laid and the system is expected to serve more than 100 non-residential buildings.

The district cooling system has a coverage area of 320 hectares in the ex-Kai Tak airport, and has a total design cooling capacity of 284 megawatt of refrigeration, or 80,800 RT. This capacity translates to a cooling supply for 40 30-story high commercial buildings. The district cooling system comprises two central chiller plants – the North Plant and the South Plant. The advantage of having multiple plants is that the distance between chiller plants and consumers is reduced, hence cooling loss during conveyance is also reduced. The chilled water pipes have a 65mm insulation layer and buried underground to further help minimise cooling loss. According to a study by EMSD, the district cooling system is estimated to consume 35% less electricity compared to traditional air-cooled air-conditioning systems, and 20% less electricity compared to individual water-cooled air-conditioning systems. Ultimately, it is estimated the Kai Tak district cooling system will achieve an annual electricity saving of 85 million kWh, and a corresponding reduction of 59,500 tons of carbon dioxide emissions per year.

The district cooling system utilises sea water as a condensing medium to produce chilled water at the central plants, rejecting waste heat into the sea. This design is more efficient than traditional cooling tower option as seawater has lower temperature and helps to reduce the urban heat island effect in the Kai Tak area.

Most buildings served by the Kai Tak district cooling system are new build, but existing buildings can also be connected to the system, as seen in the case of EMSD Headquarters. This was connected to the system, replacing its chiller plant in mid-2017.

Information provided by Hong Kong District Cooling

3.

Retrofit Calculator Manual

3. Retrofit Calculator Manual

The Retrofit Calculator was designed with the following principles in mind:

- **Adaptability**: should be adjustable according to the building types that contribute to significant parts of Hong Kong's energy consumption
- **Accessibility**: should be easy to use, by requiring only simple input parameters, and generating easy to understand results
- **Scalability**: the analysis and results should be able to be scaled to the building size specified by users
- **Updateability**: the key assumptions such as energy cost, carbon intensity and capital cost should be adjustable and updateable by users in the future, if alternative assumptions are preferred
- **Velocity**: should be able to generate results quickly, as the existing industry practices take a long time.

The methodology behind the Retrofit Calculator can be found at Appendix D.

3.1 Operation of the Retrofit Calculator (Office and Hotel Versions)

3.1.1 Input

Retrofit Calculator Office Version – Building Parameters ("Input" tab in Excel)

BUILDING INFORMATION	
Office Type	1
Typical Floor Area - GFA (m2)	1000.0
Number of Floors	20
Aspect Ratio	1.0
Main Orientation	North/South
Common Area Ratio	25%
Chiller/Air Conditioning Unit Efficiency (COP)	4.00
Miscellaneous - Lift	
Lift Number	5
Lift Type	Traction
Rated Load per Lift (kg)	1276 to 2000
Miscellaneous - Non-occupied Spaces	
Carpark Provision	Yes
Carpark Ventilation	Mechnical Ventilation
Carpark Floor Height (m)	3.6
Carpark Area (m2)	2000.0
Toilet Area / Floor - GFA (m2)	20.0
Area Available for PV Panels (m2)	500.0
Upgrade Options	**LED lighting in landlord areas**

TIP: You can click the blue "i" icon (i) for more details in certain parameters.

1. **Office Type** – choose your building type (1, 2 or 3, more details in Table 1).
2. **Typical Floor Area (GFA)** – the area in squared meters (m^2) for each floor, we assume each floor has the same area and the floor shape is rectangular.
3. **Number of Floors** – number of office floors in your building, excluding carpark.
4. **Aspect Ratio** – your building's main façade length divided by side façade length.
5. **Main Orientation** – the direction your building's main façade faces.
6. **Common Area Ratio** – the average common area on each floor divided by the floor area, in percentage (%)
7. **Chiller/Air Conditioning Unit Efficiency (COP)** – the coefficient of performance of your building's chiller plant or air conditioning system.

   Please Note: while the Retrofit Calculators have been modelled to reflect the variability of air conditioning systems as much as possible, they may not match your building systems perfectly. For example, your building may have fan coil units paired with a water-cooled chiller plant. In this case, you can select Office Type 2 (assumed to have air-cooled chillers and fan coil units), and input the COP of your chiller plant manually then reduce it by 1 to 1.5 (accounting for the additional equipment required for operating a water-cooled chiller).
8. **Lift Number** – total number of lifts in your building, we assume all lifts are operating on all floors (the floor number you entered for "Number of Floors").
9. **Lift Type** – the lift type in your building, Hydraulic or Traction.
10. **Rated Load per Lift** – the rated load of your lifts in kilograms (kg).
11. **Carpark Provisions** – whether your building has a carpark or not.
12. **Carpark Ventilation** – whether your carpark has mechanical, natural or no ventilation.
13. **Carpark Floor Height** – height of each carpark floor in meters (m).
14. **Carpark Area** – total carpark area (if your carpark has more than 1 floor, please add their areas up) in square meters (m^2).
15. **Toilet Area / Floor (GFA)** – toilet area on each floor in square meters (m^2).
16. **Area Available for PV Panels** – on rooftops only.
17. **Upgrade Options** – choose one of the energy saving initiatives from the dropdown list to look at its performance in your building. Please note that some options are disabled for certain building types.

Retrofit Calculator Office Version – Financial Parameters ("Input_Finance & Others" tab in Excel)

1. **Select whether default values are to be used.**
   - Default capital costs may either be for an end-of-life scenario or for a fully functional equipment scenario. Refer to Table 2 in Section 2.1 for details.
2. **If not, the cells in orange can be edited:**
   - Electricity cost
   - Capital cost of the selected upgrade option
   - Carbon emission factor for electricity

Use Default Values		No
Financial Assumptions		**Unit**
Tariffs expected to change in future?		No
Electricity Cost	1.132	HKD/kWh
Initial Cost of Upgrade Option	204,000	HKD
Carbon Emission Factor		**Unit**
Electricity	0.6	$kgCO_2/kWh$
Other Assumptions (view only)		**Unit**
Remaining Building Lifetime	20	years

Legend
Input Cells

3. **If you would like to manually input expected electricity and gas costs for the next 20 years, please choose "Yes" in the "Tariffs expected to change in future" box.**

Long Term Energy Cost Input																					
Year after Renovation	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Units
Electricity	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	$/kWh

4. **Click the Reset Inputs button on the top if you wish to return all editable values back to their default values.**

Retrofit Calculator Hotel Version – Building Parameters ("Input" tab in Excel)

GUESTROOM TOWER		
Typical Floor Area in GFA (m^2)		2200.0
Number of Floors		20
Occupancy Rate (%)		70%
Percentage of Guestroom Area (%)		70%
Lift Number		5
Lift Type		Traction
Rated Load per Lift (kg)		1276 to 2000
PODIUM		
Total Podium Floor Area in GFA (m^2)		9320.0
PODIUM - INDOOR		
Area Schedule		Area (m^2)
Lobby, Reception	4%	373
Business Centre	2%	186
Dining/Bar/Staff Canteen	8%	746
Kitchen	8%	746
Multi-function	9%	839
Spa	8%	746
Gym	3%	280
Circulation	42%	3,914
BOH Office	6%	559
Laundry	2%	186
Server Rooms	5%	466
Others (storage, plant etc)	3.0%	280
PODIUM - OUTDOOR		
Swimming Pool Provision		Yes
Swimming Pool Area (m^2)		500.0
Carpark Provision		Yes
Carpark Ventilation		Mechnical Ventilation
Carpark Floor Height (m)		3.0
Carpark Area (m^2)		2000.0
Chiller Plant		
Existing Chiller Efficiency (COP)		3.3
RENEWABLE ENERGY		
Area Available for PV/Solar Hot Water (m^2)		1100.0
UPGRADE OPTION		**LED lighting in landlord areas**

TIP: You can click the blue "i" icon (i) for more details in certain parameters.

1. **Typical Floor Area (GFA)** – the area in square meters (m^2) for each floor, we assume each floor has the same area and the floor shape is rectangular.
2. **Number of Floors** – the number of floors in your hotel, excluding carparks.
3. **Occupancy Rate** – average percentage of guestrooms that are occupied during a typical hotel operation.
4. **Percentage of Guestroom Area** – the average guestroom area on each floor divided by the floor area, in percentage (%)
5. **Lift Number** – total number of lifts in your building, we assume all lifts are operating on all floors (the floor number you entered for "Number of Floors").

6. **Lift Type** – the lift type in your building, Hydraulic or Traction.
7. **Rated Load per Lift** – the rated load of your lifts in kilograms (kg).
8. **Total Podium Floor Area in GFA** – total podium area (if your podium has more than 1 floor, please add their areas up) in square meters (m^2).
9. **Podium Area Schedule** – the percentage of areas attributed to different purposes. Please note that the "others (storage, plants etc.)" percentage will be automatically adjusted to fill up 100%.
10. **Swimming Pool Provision** – whether your hotel has a swimming pool or not.
11. **Swimming Pool Area** – the total area of the swimming pool (if your hotel has more than 1 swimming pool, please add their areas up).
12. **Carpark Provision** – whether your hotel has a carpark or not.
13. **Carpark Ventilation** – whether your carpark has mechanical, natural or no ventilation.
14. **Carpark Floor Height** – height of each carpark floor in meters (m).
15. **Carpark Area** – total carpark area (if your carpark has more than 1 floor, please add their areas up) in square meters (m^2).
16. **Existing Chiller Efficiency** – the coefficient of performance of your hotel's chillers.
17. **Area Available for PV Panels / Solar Water Heating Systems** – on rooftops only.
18. **Upgrade Option** – choose one of the energy saving initiatives from the dropdown list to look at its performance in your hotel building. Please note that some options are disabled for certain building types.

Retrofit Calculator Hotel Version – Financial Parameters ("Input_Finance & Others" tab in Excel)

1. **Select whether default values would be used.**
   - Default capital costs may either be for an end-of-life scenario or for a fully functional equipment scenario. Refer to Table 2 in Section 2.1 for details.
2. **If not, the cells in orange can be edited:**
   - Electricity and Towngas costs
   - Capital cost of the selected upgrade option
   - Emission factors for electricity and Towngas

Use Default Values		No
Financial Assumptions		**Unit**
Tariffs expected to change in future?		No
Electricity Cost	1.132	HKD/kWh
Towngas Cost	0.24	HKD/MJ
Initial Cost of Upgrade Option	511,545	HKD
Carbon Emission Factor		**Unit**
Electricity	0.60	$kgCO_2/kWh$
Towngas	3.14	$kgCO_2/unit$
Other Assumptions (view only)		**Unit**
Remaining Building Lifetime	20	years

Legend
Input Cells

3. If you would like to manually input expected electricity and gas costs for the next 20 years, please choose “Yes” in the “Tariffs expected to change in future” box.

Long Term Energy Cost Input																					
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Units
Electricity	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	1.132	$/kWh
Gas	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	$/unit

4. Click the **Reset Inputs** button on the top if you wish to return all editable values back to their default values.

3.1.2 Output

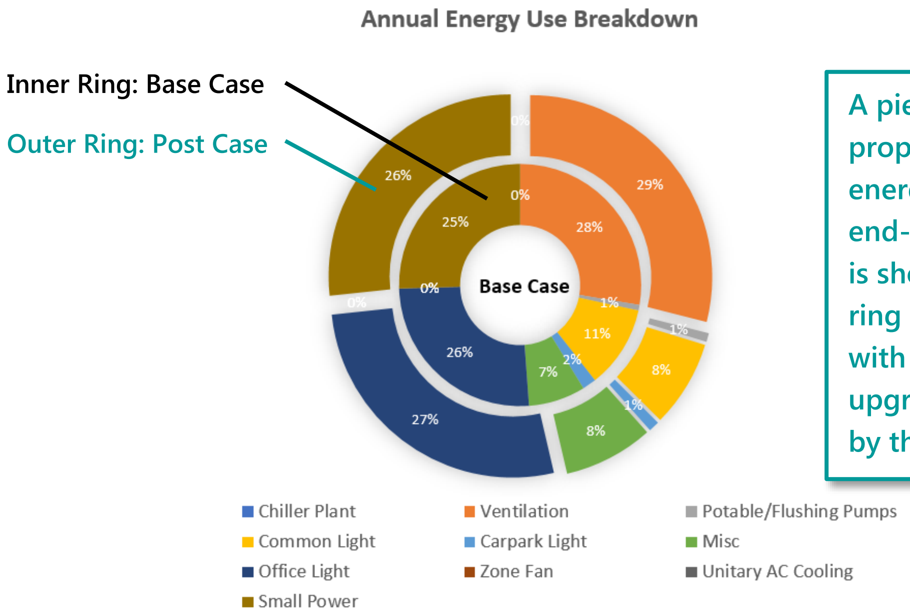
To view the results, click on the “Result for Selected Option” tab and a report containing information in the following 5 categories, will be automatically generated.

A. Summary of Key Input and Output Parameters

SUMMARY		
	Annual Energy Usage (kWh)	Equivalent CO2 Emission (kg)
Base Case	7,585,463	5,309,824
Post Case	6,503,312	4,552,318
Buidling Type	Office - Type 2	
Upgrade Option	Design to 300lux	
Total Energy Saving (kWh/year)	1,082,151	
Energy Saving (Landlord)	315,579	
Energy Saving (Tenant)	766,572	
Overall Energy Saving (%)	14.3%	
Capital Cost (HK$)	$838,500	
Average Annual Energy Cost Savings (HK$)	$1,224,995	
Payback Period (Year)	0.7	

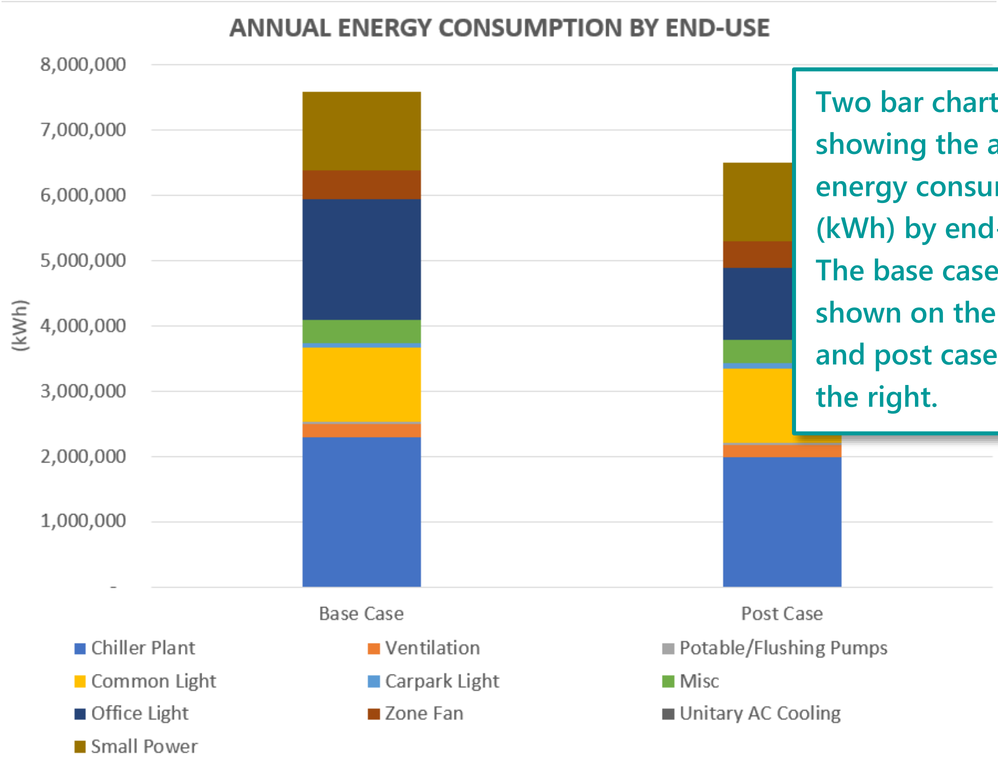
A summary table showing the upgrade option selected, modelled cost and energy savings data based on the building parameters specified by the user.

B. Annual Energy Use Breakdown Graph



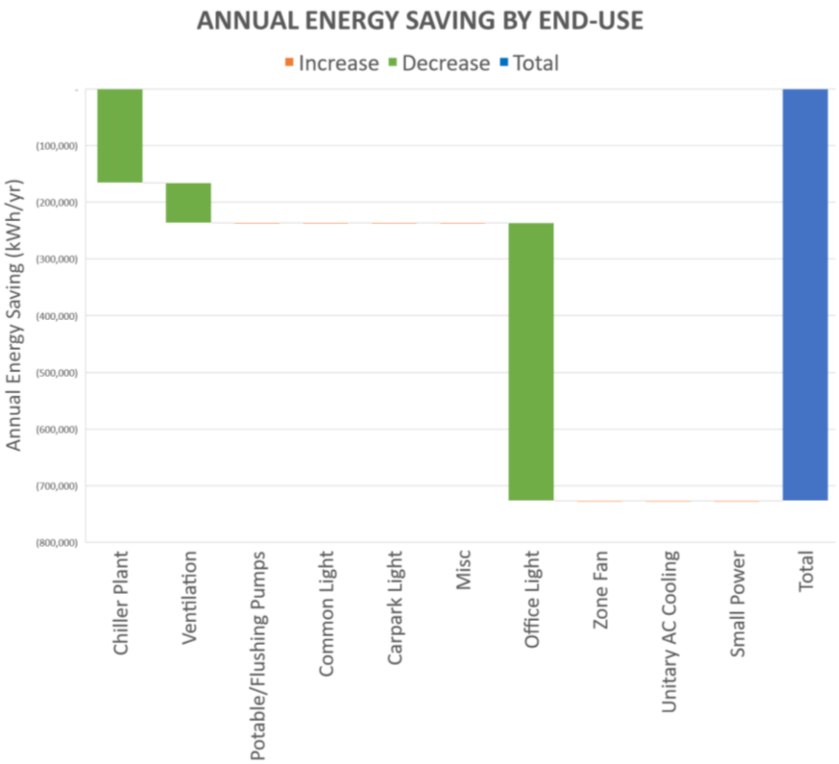
A pie chart showing the proportion (%) of annual energy consumption by end-use. The base case is shown by the inner ring and the post case with the retrofitted upgrade option is shown by the outer ring.

C. Annual Energy Consumption Graphs



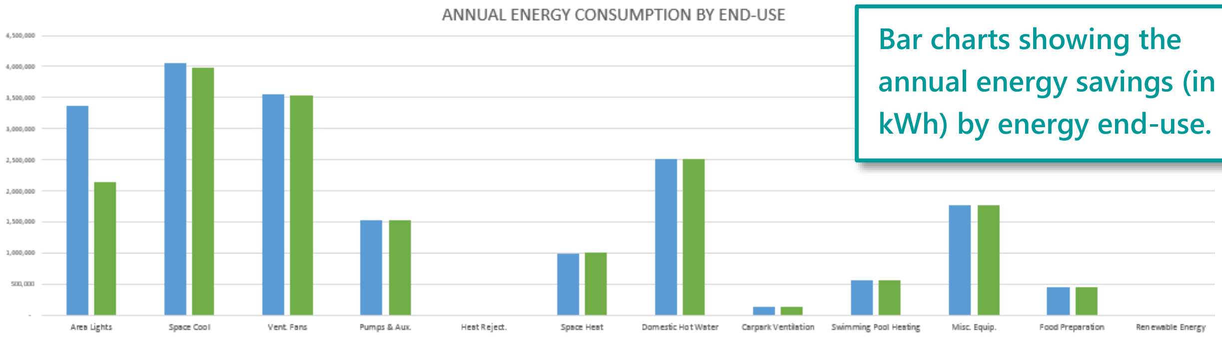
Two bar charts showing the annual energy consumption (kWh) by end-use. The base case is shown on the left and post case on the right.

D. Annual Energy Savings Graphs (works only with Excel in the Office 365 version)



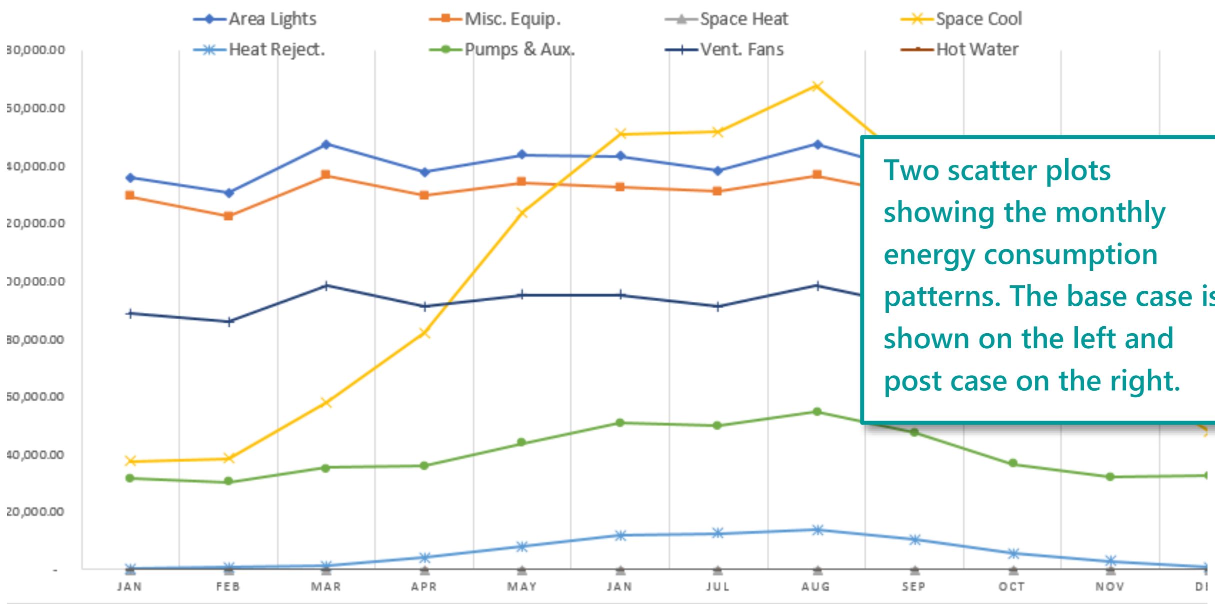
Waterfall chart showing the annual energy savings (in kWh) for different equipment types. The right-most bar shows the total savings achieved by the selected upgrade option.

E. Annual Energy Consumption Breakdown



Bar charts showing the annual energy savings (in kWh) by energy end-use.

F. Monthly Energy Consumption Graphs (one each for base case and post case)



Two scatter plots showing the monthly energy consumption patterns. The base case is shown on the left and post case on the right.

G. Result Overview Tab

There is also a "Result Overview" tab that summarises the energy saving performances of all potential upgrade options according to the specifications of your building. This tab includes a summary table, and 4 graphs showing the annual carbon, energy, cost savings and payback periods of all upgrade options. The Office Calculator breaks the annual energy savings down into landlord and tenant savings. Please click the **FILL TABLE** button to update the summary table and the graphs that follow.

If you have the retrofit cost information for your own building, that you can also input your own cost data in the **Capital Cost (HKD) (Editable)** column.

3.2 Frequently Asked Questions

Q: Why are the payback periods for certain options so high? Should I still consider them?

Yes definitely. Some options have long payback periods due to their high initial capital and/or labour costs. If your existing equipment is near its end-of-life and needs replacement, you can calculate its payback period using marginal costs or incremental costs (the cost difference between an energy efficient equipment and a like-for-like replacement of the old equipment). Please refer to the next question on how to calculate paybacks using incremental costs.

Q: How do I calculate the payback period based on end-of-life scenarios?

The default costs for certain options like glazing and lifts, shown as "end-of-life" scenarios in Table 2, are calculated based on the incremental cost of replacement. For technologies that are calculated based on full costs, you can do so in two ways:

Method 1: In the "Result Overview" tab, input the incremental cost of your desired option (cost difference between an energy efficient equipment and a like-for-like replacement of the old equipment) at the "Capital Cost (HKD) (Editable)" column.

Method 2: In the "Input_Finance & Others" tab, select "No" for the "Use Default Values" box and enter the incremental cost of your desired option.

Please note: if you use **Method 2**, the "Capital Cost (HKD) (Editable)" column in the "Result Overview" tab will not be updated automatically. Therefore, we recommend Method 1 if you wish to use the "Result Overview" tab to view cost savings and payback periods and to compare results for more than one option.

Q: Why can't I change the electricity costs in the "Input_Finance & Others" tab?

Please make sure to change the "Use Default Values" box from "Yes" to "No". If you wish to input electricity costs for the next 20 years manually, please also change the "Tariffs expected to change in future?" box from "Yes" to "No", and you will be able to input electricity costs individually.

Q: Why are the costs, energy savings and payback periods different from my actual retrofitted cases?

There are several assumptions and generalizations made to ensure that the Retrofit Calculator is easy to use for all users. Please note that the Calculator aims to provide users with approximate performances of different upgrade options for a general overview and comparative purposes, and not exact figures.

Q: Why do I need to input the building's main orientation?

This will be used to determine the amount of cooling your building requires, as the building orientation will affect the amount of heat received by your building throughout the year.

Q: Will the data I input be collected in any way?

No. We do not and will never collect any buildings data inputted into our Retrofit Calculator. The Calculator is solely operated on the client-side and does not require internet connection to operate. We do, however, welcome your feedback and comments on our Calculator via http://bec.org.hk/resource-centre/eerguide_download.

Q: Why can't I choose all 22 upgrade options that are mentioned in the Guide?

The available upgrade options depend on building types, so options that are not applicable to the building type selected will not be shown. For example, the "solar pool heating" option will only be available tor hotel buildings but not office buildings.

Q: Why do I see "#N/A" for Energy Savings in my results?

This happens when you select an upgrade option that isn't applicable to the building type you choose. Please make sure you choose the correct building type before selecting an upgrade option (the options will adjust automatically). Please also make sure you don't leave the "Chiller/Air Conditioning Unit Efficiency (COP)" input blank.

Q: [Office Version] What energy uses are included in the landlord and tenant lists respectively?

They vary slightly across office types as follows:

Office Type 1

Landlord: cooling, ventilation, common lighting, potable and flushing water pumps, vertical transport, exhaust fans

Tenant: lighting and small power in office area

Office Type 2

Landlord: cooling, ventilation (except fan coil in office area), common lighting, potable and flushing water pumps, vertical transport, exhaust fans

Tenant: lighting, fan coils and small power in office area

Office Type 3

Landlord: common lighting, potable and flushing water pumps, vertical transport, exhaust fans

Tenant: cooling, lighting, fan coils and small power in office area

Q: Why aren't my results in the "Results Overview" tab updating?

Only the changes made in the "Capital Cost (HKD) (Editable)" column in the "Results Overview" will automatically update the cost savings and payback periods on that tab. To update the results based on any changes in the "Input" and "Input_Finance & Others" tabs, please click the **FILL TABLE** button in the "Results Overview" tab and the results will be refreshed.

Q: Why don't capital costs change in the "Results Overview" tab when I manually put them into the "Inputs_Finance & Others" tab?

The capital cost in the "Inputs_Finance & Others" is only taken into account in the "Result for Selected Option" tab. You will need to click the **FILL TABLE** button, and then manually change the "Capital Cost (HKD) (Editable)" column in the "Results Overview" tab.

Q: Why am I not getting reasonable results or get an error after I click the FILL TABLE button in the "Results Overview" tab?

You may have missed an input in the "Input" or "Inputs_Finance & Others" tab. The COP of the existing chiller has been left out for you to input manually. Please go back and double check that all inputs are complete before clicking the button again.

3.3 Assumptions in the Retrofit Calculator

- Building geometry is rectangular
- Base case building fabric complies with Hong Kong OTTV code requirement[25]
- Office air conditioning systems:
  - centralised water-cooled chiller plant with VAV in office space for Type 1
  - centralised air-cooled chiller with fan coils in office space for Type 2
  - split type air conditioning systems for Type 3
  - the coefficient of performance (COP) of chillers are specified by users
- Hotels air conditioning systems:
  - centralised air-cooled chiller with fan coils in guestrooms
  - for podium: air-handling units (AHUs) in dining/bar/staff canteens, gym, and lobby and reception; primary air-handling units (PAUs) with fan coil units (FCUs) for other rooms
- Occupied areas face outwards from the building with windows on all walls.
- Main elevations of buildings are along the north/south, east/west, southeast/northwest, southwest/northeast directions.
- Maintenance costs have been excluded
- Indoor temperature set point is 24°C
- Energy savings are calculated based on the differences in the base cases and retrofitted cases (details listed in Appendix A)

3.4 Limitations of the Retrofit Calculator

Fixed Building Systems and Types

The Calculator only allows an analysis of retrofit options for certain building types with fixed building systems, including air conditioning, lighting and façade systems. The Calculator does not provide the option for users to modify the base building systems. The covered building types

[25] http://www.bd.gov.hk/english/documents/code/e_ottv.htm

and system combinations have been selected as they represent most of the building stock within Hong Kong, and are intended for users to choose a building type that matches best to their own buildings. The results generated are intended to be indicative of the relative impact of energy retrofit options sufficient for the user to determine their next course of action.

As the analyses involved requires energy modelling, the Calculator cannot analyse the impact of retrofit options for base buildings with the exact characteristics of their own building, unless they coincide with the options provided in the Calculator. For a more detailed analysis, the user would need to engage an energy consultant. However, as the intent of the Calculator is to provide an indicative analysis without the need for comprehensive energy modelling, there is no need for the Calculator to completely match all possible building-system combinations.

The assumption of Near End-of-life Scenarios for Certain Equipment

Some upgrade options are assumed to be replaced near their end-of-life, such as chiller and lifts (refer to Table 2, Section 2.1), so that default costs adopted in the payback analyses of these options reflect the period required to pay back the cost difference between efficient equipment and less advanced, lower efficiency equipment (i.e. marginal cost or incremental cost). To carry out an analysis of total equipment cost (such as when equipment is still functional), the total equipment and labour costs can be manually input by the user to analyse the associated payback.

Impact Analysis of Individual Strategies

The Calculator only shows the impact of implementation of each energy retrofit option in isolation. The Calculator cannot generate results to show the impact of the implementation of combinations of two or more of the various options. However, a rough estimation of the impacts can be made by summing the effects of different options of interest.

No Direct Comparison between Strategies

The Calculator has been set up to display the estimated building performance of individual energy retrofit options. It does not output a comparison of two or more options simultaneously. Any comparison of different options can be carried out by referring to the generic MAC curve as provided in this report.

Generic Costing Assumptions

The analysis on economic viability of different options is based on costing data derived from the Cundall Hong Kong Limited project team's experience and government sources. However, these may not represent the cost quotations that are available to the user as the cost of various technologies may change, particularly as new products enter the market. Thus, the Calculator allows the users to input their own costs into the Calculator to allow a more accurate analysis of\r their cases.

No Feed-In-Tariff Input

As there are no finalised feed-in-tariffs at the time of development of the Calculator, it does not consider the effects of a feed-in-tariff on the economic viability of various energy retrofit options, in particularly photovoltaic systems.

Retail Spaces Not Considered

The Calculator does not consider retail spaces for the following reasons. Firstly, retail spaces in Hong Kong normally exist in mixed building types on either the lower floors of buildings or under office or residential towers in podia. Secondly, there are large numbers of possible variations in retail areas of buildings.

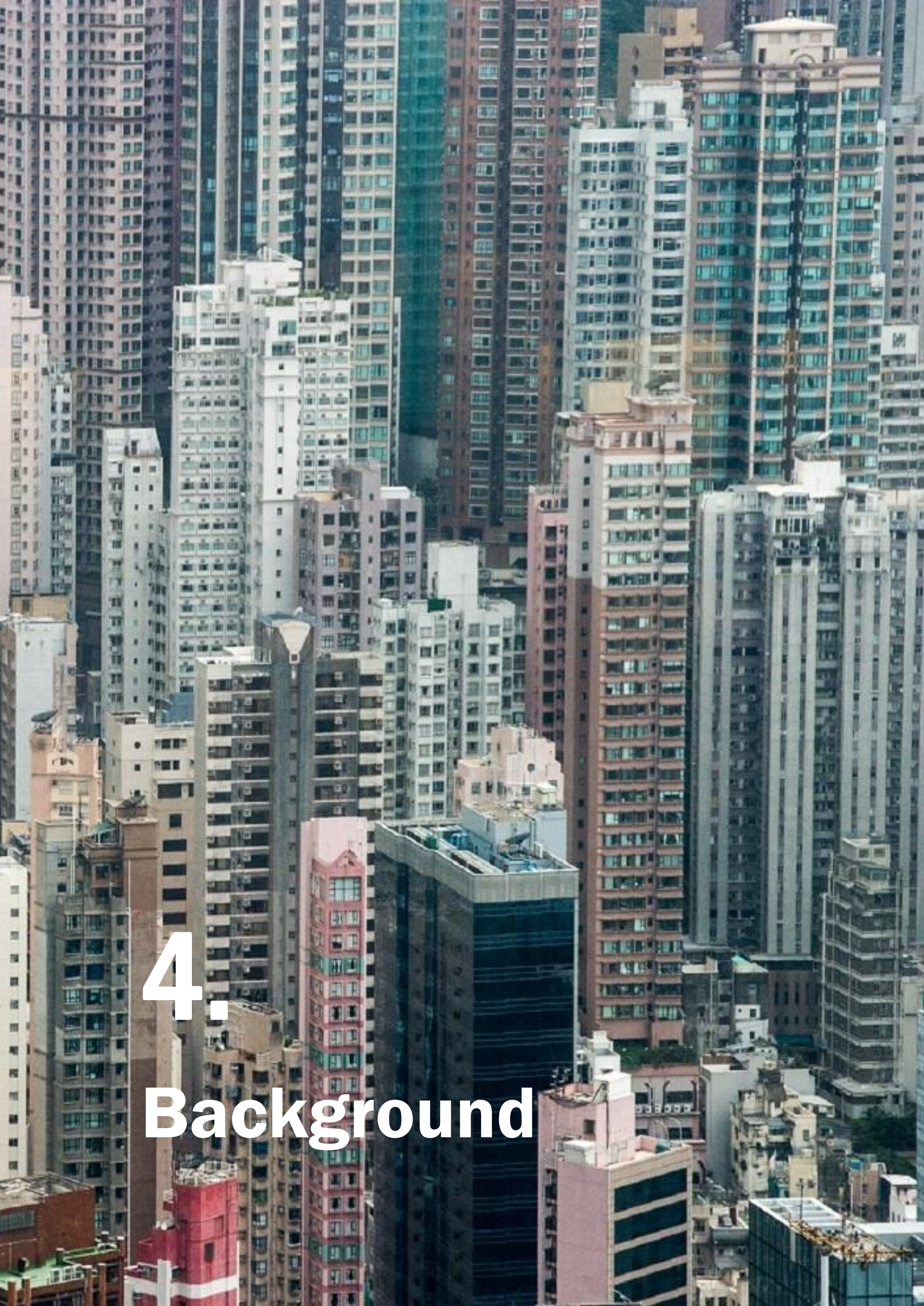
The omission of retail from the scope of the Calculator is beneficial to users. On the one hand, the complexity of the model, its inputs and outputs are kept to a minimum, thus keeping the decision-making process leading from usage of the model simple. On the other hand, the analysis allows the savings due to retrofits in one space type in mixed use buildings to be isolated.

Simple Payback Analysis

The Calculator only calculates the simple payback in its financial analysis of the options. This is due to the wide possible range of weighted average cost of capital (WACC), which is understood to be normally adopted by companies as the discount rate/interest rate in their financial analyses. Furthermore, as the WACC is generally higher than the inflation rate, accounting for discount and inflation rates in the payback analysis will result in a longer payback period, and does not offer more information. Thus, simple payback has been utilised in order to provide an indication of the effectiveness of the strategies studied to provide a financial return.

Rough Estimates of Tenant and Landlord Benefits

Due to the large variety of tenant/landlord contract arrangements, particularly with renovation responsibilities and electricity bill arrangements, it is difficult to be precise as to the effect of many of the options on landlords and tenants. Thus, the energy and cost savings for tenants and landlords have been broken down according to assumptions as detailed in Section 3.2. Any variations to these assumptions will require further analysis.



4. Background

4. Background

4.1 Climate Change – Trends and Impacts

Climate change poses an unprecedented global challenge, and its effects are already being experienced worldwide. The World Meteorological Organization ranked 2016 as the hottest year on record, with average global sea surface temperatures also at a record high. January-February 2017 had the lowest average sea ice in the Arctic and Antarctic on record[26].

Hong Kong is experiencing its share of climate-related effects. Winter 2016-2017 was one of the warmest on record: the mean temperature from December to February reached 18.4°C. The annual mean temperature for 2016 was 23.6°C, 0.3°C higher than the norm, while the annual total rainfall of 2016 was 3,026.8 millimetres, 26% above the norm[27].

The local impacts of climate change are far-reaching, as described in BEC's *Hong Kong Climate Resilience Roadmap for Business*[28]. The five main impacts for Hong Kong businesses, direct and indirect, are:

1. Flooding and landslides: from storm surge, sea level rise and heavy rainfall,
2. Heat stress: impacting on buildings and people
3. Water scarcity: people and business
4. Health: heatstroke and disease
5. A compromised supply chain

For details of these impacts, please refer to the above report. These impacts are considerably more severe if the temperature rise is above 2°C as shown in Figure 10 below on the key climate variables.

Figure 10: Climatological Impacts of Different GHG Concentration Scenarios[27]

[26] http://www.hko.gov.hk/press/WP/2017/pre20170323.htm
[27] http://www.hko.gov.hk/press/WP/2017/pre20170323.htm
[28] http://bec.org.hk/files/images/Resource_Centre/Publications/BEC_Hong_Kong_Climate_Resilience_Roadmap_for_Business_report.pdf
[29] From Hong Kong Observatory's presentation slides.

4.2 Global Climate Change Policy

The Paris Climate Change Agreement, entered into in December 2015 by 197 countries, came into force in record time on 4 November 2016. As of November 2017, it had already been ratified by 170 parties[30]. Its overarching objective is to keep the global temperature rise below 2°C above pre-industrial levels to avoid severe climate change, but endeavouring to limit the temperature rise to less than this - below 1.5°C[31] considering the substantial impacts of this additional 0.5°C degree rise.

To achieve this, the Agreement states that greenhouse gas emissions ("GHG emissions") need to be "net zero" in the second half of the century. That means that any greenhouse gases that are emitted need to be compensated for by absorption through forestry or other means.

The Paris Agreement is regarded as a game changer in that all countries in the world recognise their responsibility to take action to address climate change – not just the richer countries. Each country sets its own targets, with richer countries on the whole setting stricter targets.

4.3 China and Hong Kong's Overarching Climate Policies

As a signatory of the Paris Agreement, China for the first time made a firm GHG reduction commitment – it's nationally determined contribution (NDC). Its NDC includes: peaking CO_2 emissions by 2030 at the latest; reducing carbon intensity of GDP by 60-65% from 2005 levels by 2030; increasing energy generation from non-fossil fuel sources to around 20%; and increasing forestry stocks by around 4.5 billion m^3 from 2005 by 2030. China's commitment to reduce emissions is reinforced by measures set forth in the 13th 5-Year Plan which include policies as to energy generation, growth sectors of the economy, energy efficiency as well as its cities plans[32].

As decided by the Central People's Government, the Paris Agreement applies to Hong Kong too. Building on its 2010 target and mirroring China's NDC goals, in early 2017, the Hong Kong SAR Government published its Climate Action Plan 2030+. It set a target to reduce the carbon intensity of the economy (i.e. of each unit of GDP) by 65-70% by 2030 from 2005 as the base year. This translates to a 26-36% reduction in absolute emissions.

4.4 Buildings Energy Efficiency: Why So Critical to Climate Change?

Buildings are the largest energy consuming sector in the world, accounting for one-third of total final energy use[33]: 40% of electricity[34] and 22% of natural gas[35] consumed globally. As a result,

30 http://unfccc.int/paris_agreement/items/9485.php
31 http://unfccc.int/paris_agreement/items/9485.php
32 http://appc.ccchina.gov.cn/archiver/APPC/UpFile/Files/Default/20160707172605704491.pdf
33 http://www.iea.org/publications/freepublications/publication/Building2013_free.pdf
34 https://www.hkgbc.org.hk/upload/7.Resources/HKReport2017/HK-Report-2017_e-book_double-page.pdf
35 https://www.worldenergy.org/wp-content/uploads/2017/03/WEResources_Natural_Gas_2016.pdf

about one-third of energy-related CO_2 emissions[36] and 19% of GHG emissions globally can be attributed to buildings[37].

In a business-as-usual scenario, buildings energy demand would rise by almost 50% between 2010 and 2050[38]. Hence, managing energy usage within buildings is vital to any long-term strategy to reduce overall greenhouse gas emissions.

To achieve the goal of net zero emissions, limiting temperature rise to 2°C, the International Energy Agency estimates that a 77% reduction in total CO_2 emissions from buildings by 2050 is required from 2010 levels[39]. Assuming a 50% reduction in carbon intensity of energy, this still requires a reduction in energy usage of 54% within this timeframe.

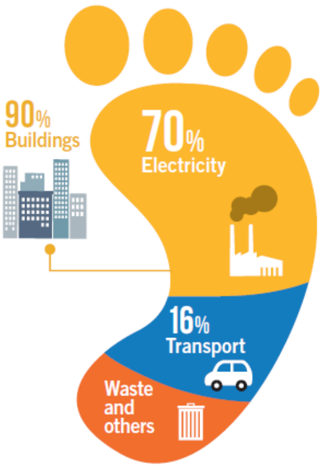


Figure 11: Hong Kong's Carbon Footprint Breakdown[40]

In the case of Hong Kong, 91% of our GHG emissions are attributed to energy consumption – essentially electricity, gas and fossil fuels for vehicles and vessels. The remainder is attributed to waste, industrial processes, and land use.

Looking at the supply side, approximately 70% of GHG emissions are attributed to electricity generation[41]. Over 90% of Hong Kong's electricity consumption is attributable to buildings, which means that electricity used in buildings account for over 60% of the city's GHG emissions.

It should be noted that GHG emissions from gas are relatively low in Hong Kong. Approximately 5% of Hong Kong's GHG emissions are attributed to gas usage[42]. Just over half of this is related to gas consumption in buildings, a relatively low amount[43, 44].

Hong Kong has more than 50,000 buildings – approximately 42,000 buildings in the private sector and 8,000 government buildings. Given its urban density, the building sector in Hong

36 http://www.iea.org/publications/freepublications/publication/Building2013_free.pdf
37 https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_chapter9.pdf
38 http://www.iea.org/publications/freepublications/publication/Building2013_free.pdf
39 http://www.iea.org/publications/freepublications/publication/Building2013_free.pdf
40 http://www.enb.gov.hk/sites/default/files/pdf/ClimateActionPlanEng.pdf
41 http://www.enb.gov.hk/sites/default/files/pdf/ClimateActionPlanEng.pdf
42 Calculated assuming an emissions factor for electricity of 0.6kg/kWh and for gas the equivalent of 0.234 kg/kWh.
43 https://www.climateready.gov.hk/files/pdf/HKGHG_Sectors_201612.pdf
44 http://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2016.pdf

Kong is more significant than in other countries in terms of reducing GHG emissions. The importance of buildings energy efficiency is reflected in the Hong Kong Green Building Council's 2030 Plan.

4.5 Existing Commercial Buildings: Why So Important?

Commercial buildings account for the largest proportion of energy consumption in Hong Kong. Total energy consumption by commercial buildings is approximately 61% of the total energy use of all building types, whereas residential and industrial buildings consume 32% and 7% respectively[45]. 85% of the energy used by commercial buildings is electricity and around 11% is gas (see section 4.6 for further information). Figure 12 below shows that the total electricity consumption by commercial buildings is 66% of the total electricity use of all buildings, far exceeding the 28% of residential buildings and 6% of industrial buildings[46].

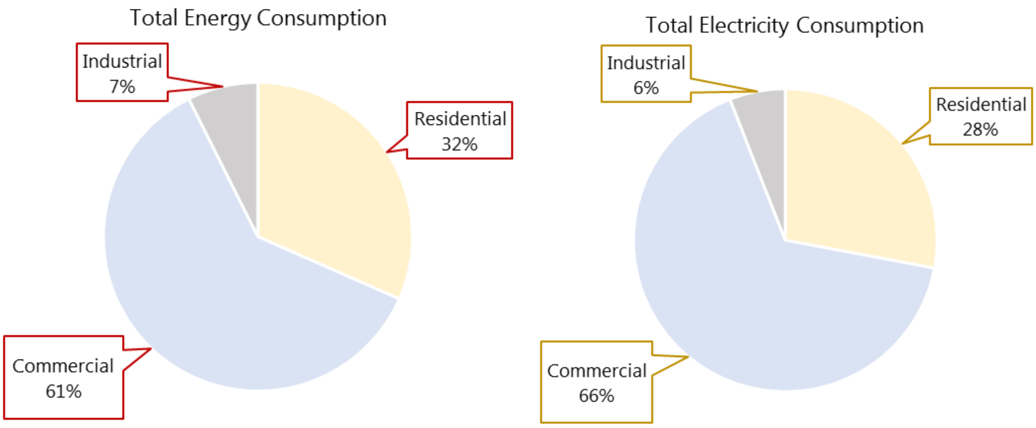


Figure 12: Total Electricity and Energy Consumption by Building Type

On a per unit area comparison, on average, commercial buildings likewise consume more energy than residential buildings. While commercial buildings energy utilization varies depending on building subtype, they can consume up to 6,622 MJ/m^2/year, whereas the most energy intensive residential buildings only consume 528 MJ/m^2/year in comparison[47]. Projections suggest that commercial buildings on a business as usual trajectory are likely to continue to be more energy intensive than residential buildings. By 2030, HKGBC estimate that commercial buildings will consume two to ten times more electricity per unit area compared to residential buildings, depending on commercial building subtype[48].

In summary, in Hong Kong the commercial buildings sector is the single biggest consumer of energy; and within the building sector, there is the greatest opportunity to reduce the energy consumption from existing commercial buildings. It has been estimated that 58% of buildings electricity demand will come from existing commercial buildings by 2030[49]. Improvements on

45 http://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2016.pdf
46 http://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2016.pdf
47 http://ecib.emsd.gov.hk/en/index.htm
48 https://www.hkgbc.org.hk/ebook/HKGBC_Roadmap/files/assets/common/downloads/HKGBC_Roadmap.pdf
49 https://www.hkgbc.org.hk/ebook/HKGBC_Roadmap/files/assets/common/downloads/HKGBC_Roadmap.pdf

this front will be important towards Hong Kong achieving its climate and energy targets, as shown in Figure 13 below.

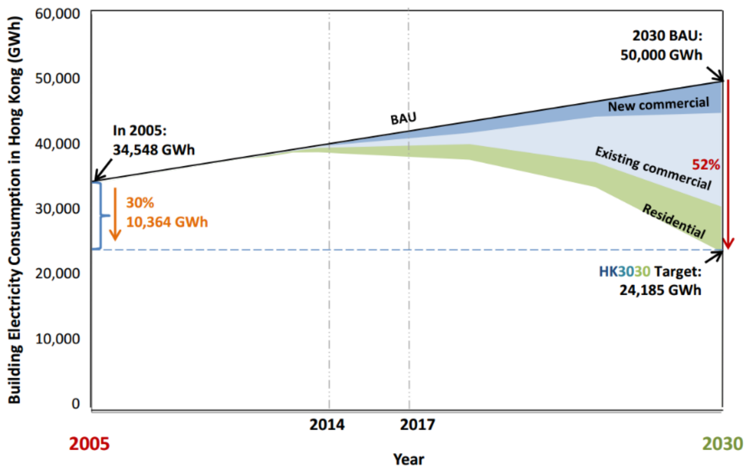


Figure 13: Buildings Electricity Consumption Prediction by 2030[50]

4.6 Usage of Different Fuel Types in Commercial Buildings

The majority of energy consumption within Hong Kong's commercial buildings is electricity. Gas accounts for a little over 11% as shown in Figure 14. Moreover, more than 90% of GHG emissions from commercial buildings is from electricity, while GHG emissions from gas account for approximately 5%. Hence, this Guide focuses on efficiency in terms of electricity consumption.

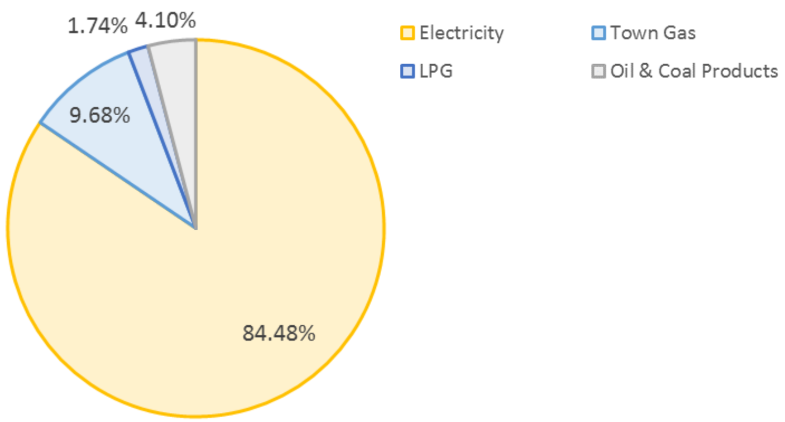


Figure 14: Commercial Building Energy Consumption by Fuel Type[51, 52]

Currently, the GHG emission factors by fuel type are as shown in Figure 15 below. However, the emission factor for electricity is expected to decrease as Hong Kong adjusts its fuel mix for electricity generation. In fact, there is great potential to significantly decarbonise electricity, but much less potential to decarbonise gas.

50 https://www.hkgbc.org.hk/ebook/HKGBC_Roadmap/files/assets/common/downloads/HKGBC_Roadmap.pdf
51 http://www.emsd.gov.hk/filemanager/en/content_762/HKEEUD2016.pdf
52 http://www.statistics.gov.hk/pub/B11000022014AN14B0100.pdf

Fuel Type	Emissions Factors	
	[kg CO_2e/MJ]	[kg CO_2e/kWh]
Electricity	0.167	0.6
Town Gas	0.065	0.234
LPG	0.064	0.23

Figure 15: GHG Emissions Factors by Fuel Type[53, 54]

4.7 Policy Framework for Buildings Energy Efficiency

As the city's greenhouse gas emissions are closely linked with energy consumption the Hong Kong SAR Government has put in place an Energy Saving Plan. This includes a target to reduce energy intensity by 40% by 2025 from 2005 levels; commitments on the part of Government buildings; and a commitment to review and upgrade the various standards in place (described below).

The Government's policy framework to promote buildings energy efficiency is as follows:

(a) Gross Floor Area concession for New Buildings: this is granted up to a maximum of 10% as long as the building is subject to a BEAM Plus assessment and meets the specified pre-requisites.

(b) The Building Energy Codes: Under the Buildings Energy Efficiency Ordinance ("BEEO") 2012, newly constructed buildings or major retrofits must comply with codes in relation to four types of building services installations: air-conditioning, lighting, electrical, and lift and escalators.

(c) Energy Audits: The BEEO also requires the owners of commercial buildings to conduct energy audits of central building services installations of buildings for at least every 10 years in accordance with the Energy Audit Code.

(d) Mandatory Energy Efficiency Labelling Scheme (MEELS): Through the Energy Efficiency (Labelling of Products) Ordinance 2009, products covered by MEELS such as air-conditioners, refrigerators, compact fluorescent lamps, washing machines, and dehumidifiers are required to be labelled. The coverage of the labelling scheme is expected to be expanded to televisions, electric stoves and water heaters as part of Phase 3 of MEELS.

(e) Voluntary Energy Efficiency Scheme (VEELS): VEELS now covers 22 types of items – 13 electric appliances, 7 types of office equipment, 2 gas appliances, and petrol passenger cars.

Though we have this policy framework, there is still room for improvement in particular in relation to the energy performance of existing buildings. More remains to be done to align the buildings energy performance with Hong Kong's targets and the objectives of the Paris Agreement.

[53] http://www.towngas.com/en/Household/Customer-Services/Billing-Service
[54] http://www.epd.gov.hk/epd/sites/default/files/epd/english/climate_change/files/Guidelines_English_2010.pdf

4.8 Roadmap to Improving Existing Commercial Buildings

From our discussions with experts and practitioners, it is clear that there are three primary steps to improving the energy performance of existing commercial buildings. This Guide focuses on the third because of the substantial benefits that accrue from such action, as well as because good information is needed to make the business case for what can be a significant investment.

(a) House-keeping and Behaviour Change: The least-cost step, and often the first step taken. This involves general housekeeping measures and behaviour change of occupants. It may include turning off lights and air-conditioning systems when not in use, adjusting air-conditioner temperature set point, turning off computers and monitors when not in use, or cleaning air filters more frequently. Depending on existing housekeeping protocols and occupants' behaviours, this step can reduce energy consumption by up to 10%[55].

(b) Retro-commissioning: The next step which involves some expenditure of limited capital investment is retro-commissioning (more in Section 2.4.23).

(c) Retro-fitting: This involves relatively significant capital cost investment and includes replacing built-in equipment e.g. HVAC systems with more energy efficient facilities, and installing entirely new equipment that enhances that building's energy performance. At present, the most commonly used technologies to improve energy efficiency of buildings in Hong Kong include LED lights, occupancy sensors, variable speed devices, and smart controls and meters.

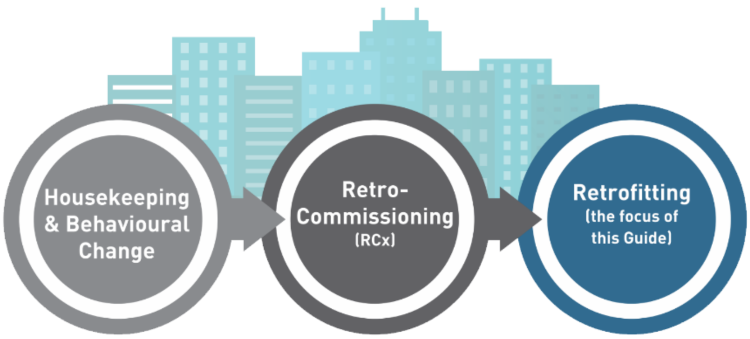


Figure 16: Steps to Improve Energy Performance of Existing Buildings

We would like to emphasise that throughout this process, it is essential to measure and record the energy performance of the building. Collecting data allows for benchmarking, reporting, identification of opportunities for improvement, and verification of improvements.

4.9 Addressing Common Barriers to Retrofitting Buildings

Based on interviews with property owners, property managers and energy advisory companies, common barriers to retrofitting buildings include:

55 https://energy.gov/sites/prod/files/2014/06/f16/change_performance.pdf

(a) Lack of buildings energy data: Many building owners and managers, especially owners and managers of older buildings, do not have sufficient information or data on energy usage in their buildings. Without understanding energy consumption patterns, it is difficult to recognise the need and identify the best opportunities to improve buildings energy efficiency.
(b) Building the business case for investment: insufficient information on the savings from using energy efficiency technologies which leads to uncertainty in returns on investment.
(c) Uncertainty in compatibility: insufficient easily-accessible information on installation, operation and maintenance phase considerations for retrofit options.
(d) Complexities in landlord, facility management and tenant interests: In most commercial buildings, there are multiple stakeholders – building owners, facility managers, and tenants. Depending on lease clauses and arrangements relating to building management there may be limited interest on the part of one or more parties to invest in the energy efficiency of buildings.

This Guide and Calculator aims to help address these issues and in this way to support the improvement of energy efficiency of buildings.

Appendices

Appendix A Assumptions used in the 22 modelled Energy Saving Initiatives

Appendix A1 Assumptions for Office Buildings

Section	Upgrade Option	Scenario	
		Base Case	Proposed Case
Façade Strategies			
2.4.1	High Performance Glazing	12mm clear glass with U-value=5.67 and Shading Coefficient (SC) =0.58 for all facade glazing	Double-glazed fenestration with U-value=2.8 and SC = 0.34 for all facade glazing
2.4.2	Solar control window film	12mm natural white glass with SC = 0.58 for all facade glazing	12mm clear glass with solar control film with SC=0.34
Lighting Strategies			
2.4.3	LED lighting in landlord areas	T8 fluorescent tube with: - Common space designed to 300lux - Toilet designed to 300lux - Carpark designed to 150lux	Replacement of T8 fluorescent tube with T8 LED with: - Common space designed to 300lux - Toilet designed to 300lux - Carpark designed to 150lux
2.4.4	Tenant Office Design to 300lux	T5 Type 1 Office: fluorescent tube designed to 500lux Type 2 Office: T8 fluorescent tube designed to 500lux	T5 fluorescent tube designed to 300lux
2.4.5	Tenant Office Lighting Control with Occupancy Sensors	No automatic sensor control	Occupancy detection control for all office tenant space
HVAC – Chiller Plant			
2.4.6	Seasonal chilled water temperature reset	Chilled water supply temperature is set at 7°C throughout the year	Chilled water setpoint raise from 7°C to 9°C when the cooling load is low enough to do so
2.4.7	Variable speed drive water-cooled Chillers	Non-VSD centrifugal water-cooled chiller (COP specified by users in the Calculator)	VSD centrifugal water-cooled chiller with COP=6.1
2.4.8	Oil-free Water-cooled Chillers	Non-VSD electric open centrifugal water-cooled chiller (COP specified by users in the Calculator)	Oil free water-cooled chiller with COP=6.7
2.4.9	Variable speed drive chilled water pumps	Decoupled circuit; CSD control for all chilled water and condenser water pumps	Decoupled circuit; CSD on primary chilled water pumps and condenser water pumps, VSD on secondary chilled water pumps

HVAC – Air-side			
2.4.10	Fresh air demand control (Office Types 1 & 2 only)	Fresh air delivered by Primary Air Handling Unit with no fresh air demand control	Fresh air delivered by Primary Air Handling Unit with VSD drive, modulate fresh air supply to each floor based on CO2 measurement
2.4.11	Plug fans (Fan wall) for AHU/PAU	AHU with centrifugal fan driven by induction AC motor through belt-pulley (Specific fan power = 2.3W/l/s)	AHU with fans driven by brushless motors with 18% fan power saving
2.4.12	DC fan coils (Office Type 2 only)	FCU specific fan power = 0.6W/l/s	FCU average specific fan power = 0.2W/l/s
2.4.13	Variable refrigerant flow or high efficiency split type (Office Type 3 only)	Ducted commercial split type AC serving all office area, with: COP=2.3 or alternative value entered by user Indoor unit Specific fan power = 0.68W/(l/s)	Ducted commercial VRF serving all office area with: COP=3.77 Indoor unit Specific fan power = 0.54W/(l/s)
2.4.14	Smart controls/BMS	No smart control provision	Smart control of chiller plant system that can reduce chiller plant water side energy by about 10%.
2.4.15	High-volume low-speed (HVLS) fans	No low speed high volume fan provision	Employ HVLS fans with 1.5m diameter for all office areas. Assume AC setpoint can be raised 2.2°C.
2.4.16	Carpark fans with VFD and CO sensor	6 ACH of supply and exhaust delivered by constant speed fans	50% fan volume reduction when CO level is lower than threshold.
Elevators			
2.4.17	High efficiency lifts	Conventional traction lift with ACVV motor (AC motor drive with variable voltage controller)	Traction lift with variable voltage variable frequency (VVVF) drive
2.4.18	Regenerative braking lifts		Conventional traction lift with ACVV motor and equipped with power regeneration drive
Hot Water and Renewable Energy			
2.4.19	Heat pumps for domestic hot water	N/A (modelled for Hotel buildings only)	N/A (modelled for Hotel buildings only)
2.4.20	Solar hot water (SHW)	N/A (modelled for Hotel buildings only)	N/A (modelled for Hotel buildings only)
2.4.21	Solar pool heating	N/A (modelled for Hotel buildings only)	N/A (modelled for Hotel buildings only)
2.4.22	Photovoltaics (PV)	No PV provision	Mono-crystalline modules with 18% efficiency installed on user-set roof area.

Appendix A2 Assumptions for Hotel Building

Section	Upgrade Option	Scenario	
		Base Case	Proposed Case
Façade Strategies			
2.4.1	High Performance Glazing	12mm clear glass with U-value=5.67 and Shading Coefficient (SC) =0.58 for all facade glazing	Double-glazed fenestration with U-value=2.8 and SC = 0.34 for all facade glazing
2.4.2	Solar control window film	12mm natural white glass with SC = 0.58 for all facade glazing	12mm clear glass with solar control film with SC=0.34
Lighting Strategies			
2.4.3	LED lighting	T8 fluorescent tube with: - Common space designed to 300lux - Toilet designed to 300lux - Carpark designed to 150lux - Kitchen designed to 500 lux - Storage and plant room designed to 200 lux	Replacement of T8 fluorescent tube with T8 LED with: - Common space designed to 300lux - Toilet designed to 300lux - Carpark designed to 150lux - Kitchen designed to 500 lux - Storage and plant room designed to 200 lux
2.4.4	Tenant Office Design to 300lux	N/A (modelled for Office buildings only)	N/A (modelled for Office buildings only)
2.4.5	Tenant Office Lighting Control with Occupancy Sensors	N/A (modelled for Office buildings only)	N/A (modelled for Office buildings only)
HVAC – Chiller Plant			
2.4.6	Seasonal chilled water temperature reset	Chilled water supply temperature is set at 7°C throughout the year	Chilled water setpoint raise from 7°C to 9°C when the cooling load is low enough to do so
2.4.7	Variable speed drive water-cooled Chillers	Non-VSD centrifugal water-cooled chiller (COP specified by users in the calculator)	VSD centrifugal water-cooled chiller with COP=6.1
2.4.8	Oil-free Water-cooled Chillers	Non-VSD electric open centrifugal water-cooled chiller (COP specified by users in the calculator)	Oil free water-cooled chiller with COP=6.7
2.4.9	Variable speed drive chilled water pumps	Decoupled circuit; CSD control for all chilled water and condenser water pumps	Decoupled circuit; CSD on primary chilled water pumps and condenser water pumps, VSD on secondary chilled water pumps
HVAC – Air-side			
2.4.10a	Fresh air demand control-primary air unit for dining, multi-function and kitchen areas	No fresh air demand control	Modulating fresh air supply according to CO_2 level. Applied to: dining, multifunction, kitchens. Minimum turn down ratio = 30%
2.4.10b	Guest room fresh air fan off-peak cycling	No fresh air demand control	Fresh air supply to guest room will be cycle off by 2 hours per day (1.00pm - 3:00pm) the supply fan.

2.4.11	Plug fans (Fan wall) for AHU/PAU	AHU with centrifugal fan driven by induction AC motor through belt-pulley (Specific fan power = 2.3W/l/s)	AHU with fans driven by brushless motors. Fan power saving=18%
2.4.12	DC fan coils	FCU specific fan power = 0.6W/l/s	FCU average specific fan power = 0.2W/l/s
2.4.13	Variable refrigerant flow or high efficiency split type (Office Type 3 only)	N/A	N/A
2.4.14	Smart controls/BMS	No smart control provision	Smart control of chiller plant system that can reduce chiller plant water side energy by about 10%.
2.4.15	High-volume Low-speed (HVLS) Fans for BOH Offices and Lobbies	No high volume low speed fan provision	Employ HVLS fans with 1.5m diameter for BOH office areas and main lobby. Assume AC setpoint can be raised 2.2°C.
2.4.16	Carpark fans with VFD and CO sensor	6 ACH of supply and exhaust delivered by constant speed fans	50% fan volume reduction when CO level is lower than threshold.
Elevators			
2.4.17	High efficiency lifts	Conventional traction lift with ACVV motor (AC motor drive with variable voltage controller)	Traction lift with variable voltage variable frequency (VVVF) drive
2.4.18	Regenerative braking lifts		Conventional traction lift with ACVV motor and equipped with power regeneration drive
Hot Water and Renewable Energy			
2.4.19	Heat pumps for domestic hot water	DHW heated by gas-fired boiler with efficiency of 80% to produce hot water at 65°C	Two stage water heating: ≤20-45°C: by heat pump 45-65°C: by gas boiler - Heat pump COP = 3.3 - Gas-fired boiler = 80% (same with Baseline)
2.4.20	Solar hot water (SHW)	Water heating is served by gas-fired boiler with 80%	Evacuated-tube solar collectors with efficiency of 60%. Size of solar collectors entered by user.
2.4.21	Solar pool heating	Water heating is served by gas-fired boiler of 80% efficiency	Evacuated-tube solar collectors with efficiency of 60%. Size of solar collectors entered by user.
2.4.22	Photovoltaics (PV)	No PV provision	Mono-crystalline modules with 18% efficiency installed on user-set roof area.

Abbreviations:

AHU = Air handling unit
BEC = Building Energy Code
BOH = Back-of-house
CO = Carbon monoxide
COP = Coefficient of Performance
CSD = Constant speed drive
DC = Direct current
PAU = Primary air handing unit
VSD = Variable speed drive
VRF = Variable refrigerant flow

Appendix B Technical Details of Buildings Modelled for Sample Studies (Section 2.2)

Office Buildings – Typical Specifications (Types 1, 2 & 3)	
Area per floor	1,000 m^2
Number of floors	20
Common Area Ratio	25%
Basement carpark area	2,000 m^2
Carpark ventilation	Mechanical
Aspect ratio	1
Number of lifts	5
Lift capacity	1,276 to 2,000 kg
Toilet area per floor	20 m^2
Remaining building lifetime	20 years
Existing Chiller COP	Type 1: 4.0 Type 2: 2.8 Type 3: 2.3

Hotel Building – Typical Specifications	
Area per floor	2,200 m^2
Number of floors	20
Guestroom area per floor1,540 m^2	
Podium area	9,320 m^2
Area distribution	Circulation 40% Back-of-house Office: 6% Lobby/Reception 4% Dining/Kitchen: 16% Functional Rooms: 10% Others: 24%
Basement carpark area	2,000 m^2
Carpark ventilation	Mechanical
Aspect ratio	1
Number of lifts	5
Lift capacity	1,276 to 2,000 kg
Toilet area ratio (relative to guestroom area)	30%
Occupancy rate	70%
Remaining building lifetime	20 years
Existing Chiller COP	3.3

Appendix C Model Output Results for Sample Studies (Section 2.2)

Appendix C1 Type 1 Office Building

Option	Description	Capital Cost	Energy Savings /year [kWh]	Cost savings /year	CO2 Emissions /year [kg]	Simple payback period [yrs]	Lifetime Comparison: Expected cost over Building Lifetime (+ve cost; -ve saving)	Lifetime Comparison: CO2 reductions over Building Lifetime [tonne]	Party with Most Benefit: Office Type 1	Party with Most Benefit: Office Type 2	Party with Most Benefit: Office Type 3
1	High Performance Glazing	$19,125,455	384,890	$435,695	230,934	43.9	$10,411,556	4,618.67	Landlord	Landlord	Tenant
2	Solar control window film	$5,919,784	384,890	$435,695	230,934	13.6	-$820,854	4,618.67	Landlord	Landlord	Tenant
3	LED lighting in landlord areas	$318,750	218,790	$247,670	131,274	1.3	-$3,678,400	2,625.48	Landlord	Landlord	Landlord
4	Tenant Office Design to 300lux	$35,090	726,109	$821,956	435,666	0.0	-$16,298,753	8,713.31	All	All	All
5	Tenant Office Lighting Control with Occupancy Sensors	$571,622	272,756	$308,759	163,653	1.9	-$5,031,944	3,273.07	All	All	Tenant
6	Seasonal chilled water temperature reset	$15,000	95,179	$107,742	57,107	0.1	-$2,139,843	1,142.14	Landlord	Landlord	-
7	Variable speed drive water-cooled Chillers	$1,363,150	403,312	$456,549	241,987	3.0	-$7,767,827	4,839.74	Landlord	Landlord	-
8	Oil-free Water-cooled Chillers	$2,606,022	539,196	$610,370	323,517	4.3	-$9,601,369	6,470.35	Landlord	Landlord	-
9	Variable speed drive chilled water pumps	$90,000	191,870	$217,197	115,122	0.4	-$4,253,930	2,302.44	Landlord	Landlord	-
10	Fresh air demand control	$3,150,000	711,218	$805,099	426,731	3.9	-$12,951,980	8,534.62	Landlord	Landlord	-
11	Plug fans for AHU (Fan wall)	$1,680,000	155,279	$175,776	93,167	9.6	-$1,835,517	1,863.35	Landlord	Landlord	-
12	DC fan coils								-	Landlord	-
13	VRF or high efficiency split type								-	-	Tenant
14	Smart controls/ BMS	$2,000,000	168,573	$190,825	101,144	10.5	-$1,816,499	2,022.88	Landlord	Landlord	-
15	High-volume low-speed (HVLS) fans	$4,350,000	361,409	$409,115	216,845	10.6	-$3,832,295	4,336.91	Landlord	Landlord	Tenant
16	Carpark fans with VFD and CO sensor	$180,000	117,062	$132,514	70,237	1.4	-$2,410,275	1,404.74	Landlord	Landlord	Landlord
17	High efficiency lifts	$0	72,214	$81,746	43,328	0.0	-$1,634,919	866.56	Landlord	Landlord	Landlord
18	Regenerative braking lifts	$250,000	72,214	$81,746	43,328	3.1	-$1,301,586	866.56	Landlord	Landlord	Landlord
19	Heat pumps for domestic hot water								-	-	-
20	Solar hot water (SHW)								-	-	-
21	Solar pool heating								-	-	-
22	Photovoltaics (PV)	$1,800,000	46,000	$52,072	27,600	34.6	$758,560	552.00	Landlord	Landlord	Landlord

Note: highlighted options are not available for this building type. The payback period does not consider discount and inflation rates, and is subject to fluctuations in the electricity tariff, and capital costs of the strategies. The paybacks for this sample result are based on a constant electricity tariff of $1.132/kWh. The emission factor is 0.6 kg/kWh.

Appendix C2 Type 2 Office Building

Option	Description	Capital Cost	Energy Savings /year [kWh]	Cost savings /year	CO2 Emissions /year [kg]	Simple payback period [yrs]	Lifetime Comparison: Expected cost over Building Lifetime (+ve cost; -ve saving)	Lifetime Comparison: CO2 reductions over Building Lifetime [tonne]	Party with Most Benefit: Office Type 1	Party with Most Benefit: Office Type 2	Party with Most Benefit: Office Type 3
1	High Performance Glazing	$19,125,455	330,094	$373,666	231,066	51.2	$11,652,127	4,621.32	Landlord	Landlord	Tenant
2	Solar control window film	$5,919,784	330,094	$373,666	231,066	15.8	$419,717	4,621.32	Landlord	Landlord	Tenant
3	LED lighting in landlord areas	$318,750	264,352	$299,246	185,046	1.1	-$4,709,919	3,700.92	Landlord	Landlord	Landlord
4	Tenant Office Design to 300lux	$35,090	1,107,897	$1,254,140	775,528	0.0	-$24,942,433	15,510.56	All	All	All
5	Tenant Office Lighting Control with (	$571,622	401,614	$454,627	281,130	1.3	-$7,949,296	5,622.59	All	All	Tenant
6	Seasonal chilled water temperature	$15,000	123,765	$140,102	86,636	0.1	-$2,787,042	1,732.71	Landlord	Landlord	-
7	Variable speed drive water-cooled C	$2,806,485	352,424	$398,944	246,697	7.0	-$5,172,386	4,933.93	Landlord	Landlord	-
8	Oil-free Water-cooled Chillers	$4,009,265	585,590	$662,887	409,913	6.0	-$9,248,483	8,198.25	Landlord	Landlord	-
9	Variable speed drive chilled water p	$90,000	235,823	$266,952	165,076	0.3	-$5,249,033	3,301.52	Landlord	Landlord	-
10	Fresh air demand control	$650,000	1,026,877	$1,162,424	718,814	0.6	-$22,598,488	14,376.27	Landlord	Landlord	-
11	Plug fans for AHU (Fan wall)	$80,000	32,680	$36,994	22,876	2.2	-$659,882	457.52	Landlord	Landlord	-
12	DC fan coils	$1,672,881	293,231	$331,937	205,262	5.0	-$4,408,241	4,105.23	-	Landlord	-
13	VRF or high efficiency split type								-	-	Tenant
14	Smart controls/ BMS	$2,000,000	220,979	$250,148	154,685	8.0	-$3,002,965	3,093.71	Landlord	Landlord	-
15	High-volume low-speed (HVLS) fans	$4,350,000	333,456	$377,472	233,419	11.5	-$3,199,446	4,668.39	Landlord	Landlord	Tenant
16	Carpark fans with VFD and CO sen	$180,000	117,062	$132,514	81,943	1.4	-$2,410,275	1,638.86	Landlord	Landlord	Landlord
17	High efficiency lifts	$0	72,214	$81,746	50,550	0.0	-$1,634,919	1,010.99	Landlord	Landlord	Landlord
18	Regenerative braking lifts	$250,000	72,214	$81,746	50,550	3.1	-$1,301,586	1,010.99	Landlord	Landlord	Landlord
19	Heat pumps for domestic hot water								-	-	-
20	Solar hot water (SHW)								-	-	-
21	Solar pool heating								-	-	-
22	Photovoltaics (PV)	$1,800,000	46,000	$52,072	32,200	34.6	$758,560	644.00	Landlord	Landlord	Landlord

Note: highlighted options are not applicable to this building type. The payback period does not consider discount and inflation rates, and is subject to fluctuations in the electricity tariff, and capital costs of the strategies. The paybacks for this sample result are based on a constant electricity tariff of $1.132/kWh. The emission factor is 0.6 kg/kWh.

Appendix C3 Type 3 Office Building

Option	Description	Capital Cost	Energy Savings /year [kWh]	Cost savings /year	CO2 Emissions /year [kg]	Simple payback period [yrs]	Lifetime Comparison: Expected cost over Building Lifetime (+ve cost; -ve saving)	Lifetime Comparison: CO2 reductions over Building Lifetime [tonne]	Party with Most Benefit: Office Type 1	Party with Most Benefit: Office Type 2	Party with Most Benefit: Office Type 3
1	High Performance Glazing	$19,125,455	194,148	$219,776	135,904	87.0	$14,729,936	2,718.08	Landlord	Landlord	Tenant
2	Solar control window film	$5,919,784	194,148	$219,776	135,904	26.9	$3,497,525	2,718.08	Landlord	Landlord	Tenant
3	LED lighting in landlord areas	$318,750	214,795	$243,148	150,357	1.3	-$3,587,959	3,007.13	Landlord	Landlord	Landlord
4	Tenant Office Design to 300lux	$35,090	1,037,724	$1,174,703	726,406	0.0	-$23,353,701	14,528.13	All	All	All
5	Tenant Office Lighting Control with Occupa	$571,622	386,635	$437,670	270,644	1.3	-$7,610,163	5,412.88	All	All	Tenant
6	Seasonal chilled water temperature reset								Landlord	Landlord	-
7	Variable speed drive water-cooled Chillers								Landlord	Landlord	-
8	Oil-free Water-cooled Chillers								Landlord	Landlord	-
9	Variable speed drive chilled water pumps								Landlord	Landlord	-
10	Fresh air demand control								Landlord	Landlord	-
11	Plug fans for AHU (Fan wall)								Landlord	Landlord	-
12	DC fan coils								-	Landlord	-
13	VRF or high efficiency split type	$3,052,447	706,639	$799,916	494,647	3.8	-$7,277,036	9,892.95	-	-	Tenant
14	Smart controls/ BMS								Landlord	Landlord	-
15	High-volume low-speed (HVLS) fans	$4,350,000	161,789	$183,145	113,252	23.8	$687,099	2,265.04	Landlord	Landlord	Tenant
16	Carpark fans with VFD and CO sensor	$180,000	117,062	$132,514	81,943	1.4	-$2,410,275	1,638.86	Landlord	Landlord	Landlord
17	High efficiency lifts	$0	72,214	$81,746	50,550	0.0	-$1,634,919	1,010.99	Landlord	Landlord	Landlord
18	Regenerative braking lifts	$250,000	72,214	$81,746	50,550	3.1	-$1,301,586	1,010.99	Landlord	Landlord	Landlord
19	Heat pumps for domestic hot water								-	-	-
20	Solar hot water (SHW)								-	-	-
21	Solar pool heating								-	-	-
22	Photovoltaics (PV)	$1,800,000	46,000	$52,072	32,200	34.6	$758,560	644.00	Landlord	Landlord	Landlord

Note: highlighted options are not applicable to this building type. The payback period does not consider discount and inflation rates, and is subject to fluctuations in the electricity tariff, and capital costs of the strategies. The paybacks for this sample result are based on a constant electricity tariff of $1.132/kWh. The emission factor is 0.6 kg/kWh.

Appendix C4 Hotel Building

Option	Description	Capital Cost	Energy Savings /year [kWh]	Cost savings /year	CO2 Emissions /year [kg]	Simple payback period [yrs]	Lifetime Comparison	
							Expected cost over Building Lifetime (+ve cost; -ve saving)	CO2 reductions over Building Lifetime [tonne]
1	High Performance Glazing	$29,362,151	670,469	$758,971	402,281	38.7	$14,182,733	8,045.63
2	Solar control window film	$9,088,285	569,926	$645,156	341,955	14.1	-$785,407	6,839.11
3	LED lighting	$829,629	968,678	$1,096,544	581,207	0.8	-$18,612,359	11,624.14
4	Design to 300lux							
5	Occupancy Sensors							
6	Seasonal chilled water temperature reset	$15,000	448,648	$507,869	269,189	0.0	-$10,142,386	5,383.77
7	Variable speed drive water-cooled Chillers	$8,349,661	1,223,265	$1,384,736	733,959	6.0	-$19,345,066	14,679.18
8	Oil-free Water-cooled Chillers	$11,928,087	1,765,904	$1,999,003	1,059,542	6.0	-$28,051,977	21,190.85
9	Variable speed drive chilled water pumps	$150,000	793,548	$898,296	476,129	0.2	-$17,815,928	9,522.58
10	Fresh Air Demand Control-Primary Air Unit	$225,000	441,007	$499,219	264,604	0.5	-$9,759,388	5,292.08
10b	Fresh Air Demand Control-Fresh Air Fan	$10,000	513,964	$581,807	308,378	0.0	-$11,626,146	6,167.57
11	Plug fans for AHU (Fan wall)	$284,373	188,298	$213,153	112,979	1.3	-$3,978,692	2,259.58
12	DC fan coils	$5,880,303	1,150,693	$1,302,584	690,416	4.5	-$18,211,286	13,808.32
13	VRF or high efficiency split type							
14	Smart controls/ BMS	$2,000,000	582,614	$659,520	349,569	3.0	-$11,190,392	6,991.37
15	High-volume low-speed (HVLS) fans	$270,280	21,429	$24,258	12,858	11.1	-$214,878	257.15
16	Carpark fans with VFD and CO sensor	$180,000	97,551	$110,428	58,531	1.6	-$1,968,563	1,170.62
17	High efficiency lifts	$0	84,115	$95,218	50,469	0.0	-$1,904,360	1,009.38
18	Regenerative braking lifts	$250,000	84,115	$95,218	50,469	2.6	-$1,571,026	1,009.38
19	Heat pumps for domestic hot water	$3,938,575	697,962	$790,093	418,777	5.0	-$11,863,282	8,375.54
20	Solar hot water (SHW)	$1,616,578	315,000	$356,580	189,000	4.5	-$5,515,022	3,780.00
21	Solar pool heating	$1,565,760	157,640	$178,448	94,584	8.8	-$2,003,199	1,891.67
22	Photovoltaics (PV)	$3,600,000	92,000	$104,144	55,200	34.6	$1,517,120	1,104.00

Note: highlighted options are not applicable to this building type. The payback period does not consider discount and inflation rates, and is subject to fluctuations in the electricity tariff, and capital costs of the strategies. The paybacks for this sample result are based on a constant electricity tariff of $1.132/kWh. The emission factor is 0.6d kg/kWh.

Appendix D Methodology of the Retrofit Calculator

Step 1: Data collection, finalisation and review

- Initiatives and building types to be analysed
    - For Office buildings, three types broadly representing a range of current building stock were modelled.
    - For hotels, there is more diversity in the different areas and functions that hotels contain. Different typical areas were modelled
- Information on the initiatives necessary for the modelling and analysis works were collected
    - Information was collected from vendors and previous project experience
    - References for typical office building operation

Step 2: Calculation and modelling works

- The energy simulation methodology detailed in the Hong Kong Performance-based Building Energy Code and Appendix G of ASHRAE 90.1 was adopted for this study with adjustments to mimic the operational scenarios
- Typical baseline building models to represent average buildings, or spaces within that building, were developed in the following agreed sectors:
    - Internal and external zones
    - Reasonable internal profiles
    - MEP system, equipment systems and facade construction that are common for typical buildings in Hong Kong
- Adjustments were made such that the energy model can reflect operation inefficiency, degradation of plant performance, obsolete building standards, overprovision, and actual operational hours. For example:
    - Increasing lighting power density (LPD)
    - Decreasing HVAC equipment efficiency and older technology
    - Less efficiency lift equipment
    - Lower performance facade and building envelope
    - Longer operation hours
- Dynamic annual simulations on the baseline models were carried out to determine:
    - Baseline annual energy consumption – **$kWh/m^2/annum$**
    - Baseline annual carbon emissions – **$CO_{2eq}/m^2/annum$**

- Variations to the baseline building models to reflect the implementation of the technologies/initiatives, while keeping all other variables identical, were run to determine:
    - Off-axis model annual energy consumption, and thereby the annual energy savings
    - Off-axis model annual carbon emissions, and thereby the annual energy savings
- Output data from the building models and financial information was used to determine for each technology/initiative and model:
    - The cost of each technology/practice per unit of energy abated per square meter - **$/kWh abated/m^2**
    - The energy abatement potential of each technology/practice per square meter – **kWh abated per year/m^2**
- The 2016 carbon emission factor of 0.6 kg CO_2-e/kWh[56] for Hong Kong was used to determine for each technology/initiative:
    - The cost of each technology/practice per unit of carbon abated per square meter - **$/ Tonnes CO_{2eq} abated per year/m^2**
    - The carbon abatement potential of each technology/practice per square meter – **Tonnes CO_{2eq} abated per year/m^2**
- Output data from the building models were utilised to create a marginal abatement cost curve (MACC) for the *typical buildings* represented by the models. The study assumes that remaining building life-cycle is 20 years.

[56] Calculated based on the weighted average of carbon emissions from the two electric power companies in Hong Kong, year 2016.
Hongkong Electric Company emissions:
https://www.hkelectric.com/en/CorporateSocialResponsibility/CorporateSocialResponsibility_CDD/Documents/SR2016E_performance_targets.pdf
CLP Power Hong Kong Limited emissions:
https://www.clp.com.hk/en/about-clp-site/media-site/resources-site/publications-site/Documents/CLP-Information-Kit-English.pdf

Useful Links

Building Energy Code (2015 Edition)
http://www.beeo.emsd.gov.hk/en/pee/BEC_2015.pdf

Buildings Energy Efficiency Ordinance (BEEO) Cap. 610
http://www.beeo.emsd.gov.hk/en/mibec_beeo_WhatsNews.html

EMSD Advanced Energy Saving Technologies – Publications
https://www.emsd.gov.hk/en/energy_efficiency/energy_analysis_and_saving_technologies/advanced_energy_saving_technologies/publications/index.html

EMSD Energy Land
http://www.energyland.emsd.gov.hk/en/home/index.html

EMSD Technical Guidelines on Retro-commissioning
http://www.energysaving.gov.hk/filemanager/template/common/pdf/rcx/2017%20TG-RCx.pdf

Energy Saving for All
http://www.energysaving.gov.hk/en/home/index.html

Hong Kong Green Building Council (HKGBC) Benchmarking and Energy Saving Tool
http://hkbest.hkgbc.org.hk/com/index.html

Acknowledgements

This project, *A Guide to Energy Efficient Retrofits of Office and Hotel Buildings* and the *Retrofit Calculator,* is the work of BEC Energy Advisory Group and is kindly funded by the Konrad-Adenauer-Stiftung.

BEC would like to thank Konrad-Adenauer-Stiftung for the generous funding, Cundall Hong Kong Limited for cost and energy savings modelling and the development of the Retrofit Calculator, BEC Energy Advisory Group, Worcester Polytechnic Institute student team, as well as other contributors that had greatly helped the writing, technical description and case studies of this Guide.

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Business Environment Council Limited ("BEC") is an independent, charitable membership organization, established by the business sector in Hong Kong. Since its establishment in 1992, BEC has been at the forefront of promoting environmental excellence by advocating the uptake of clean technologies and practices which reduce waste, conserve resources, prevent pollution and improve corporate environmental and social responsibility. BEC offers sustainable solutions and professional services covering advisory, research, assessment, training and award programmes for government, business and the community, thus enabling environmental protection and contributing to the transition to a low carbon economy.

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