



**Asia-Pacific  
Economic Cooperation**

**Advancing** Free Trade  
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# **APEC Capacity Building Workshop on Retro-commissioning (RCx) Project Final Report and Workshop Summary**

Hong Kong, China | 20-21 January 2022

**APEC Energy Working Group**

September 2023





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The APEC Workshop cum Training on Retro-commissioning was held on 20-21 January 2022 in Hong Kong, China. More than 100 delegates and experts from 11 APEC member economies attended the workshop cum training to share their knowledge and experience on RCx. The initiative is to promote timely checks on the energy performance of an existing building to identify the energy-saving potential for operational improvements. Tuning and adjusting building services systems and equipment can achieve optimal operation efficiency, leading to energy saving and carbon emission reduction. We want to thank the support from the speakers, experts and event participants.

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## 1. Background

The Asia-Pacific Economic Cooperation (APEC) member economies account for around 60% of the energy consumption around the world. Given the rapidly developing economic situation and the increasing urbanisation rate, the APEC member economies devote exceptional effort to reducing greenhouse gas (GHG) emissions and combating climate change. In 2011, the APEC member economies set a target to reduce aggregate energy intensity by 45% by 2035, with respect to 2005 as the baseline year.

According to APEC Energy Demand and Supply Outlook 8th Edition, energy consumption by the buildings sector is expected to increase by almost one-quarter in the current situation scenario (the Reference scenario (REF in short) as mentioned in the Outlook). The energy consumption by the building sector can fall slightly in the Carbon Neutrality scenario (CN in short), which means a great potential for energy intensity reduction can be resulted if the effort is made to the building sector.

Apart from having appliance energy efficiency improvements and implementing stricter building codes for the new installation, efforts can also be made to existing equipment and building. When a building has been used for a certain period, its systems often need to be more in tune due to the changes caused by additions, alterations and improvement works. Retro-commissioning (RCx, in short) is a cost-effective way to periodically check an existing building's energy performance to identify operational improvement areas that can help save energy. With such "health check-ups", building owners may fine-tune their building systems and equipment so that they can operate at optimal efficiency, thus reducing the operating costs incurred.

Given that the focuses and strategies on RCx implementation are varied among APEC region, Hong Kong, China (HKC) conducted the project "APEC Capacity Building Workshop on Retro-Commissioning (RCx)" to align different best practices through a capacity building workshop. It was to foster awareness of the importance of RCx from the perspective of energy efficiency, operational improvements and reduction of GHG emissions. The workshop was then followed by an RCx training to share the latest guidelines and best practices for promoting RCx frameworks and techniques. This report summarises the findings of the project, including the RCx implementation status of several APEC member economies and innovative technologies related to RCx, for boosting the adoption of RCx in the APEC region.

## **2. Project Objective**

The project “APEC Capacity Building Workshop on Retro-Commissioning (RCx)” aims to build the capacity of the APEC member economies in low-carbon building operation and energy technology deployment. It promotes the development of energy efficiency and low-carbon measures across the APEC region. The workshop provides a forum for the APEC member economies to share their RCx policies, guidelines, practices and tools. The ultimate goal is to reduce APEC’s aggregate energy intensity by 45% by 2035. It is believed that the initiative can help generate more employment opportunities and economic activities to accelerate the APEC region's economic recovery after the COVID-19 pandemic. The project aligns with the Energy Working Group (EWG) and Expert Group of Energy Efficiency and Conservation (EGEE&C) mandates.

## **3. Introduction of Retro-commissioning (RCx)**

In this project, the term “Retro-commissioning” (RCx) is a cost-effective and systematic process to regularly review the performance of existing buildings and identify potential operational enhancements that can help save energy and reduce energy costs. It involves a single piece of equipment or bunches of systems constituting a large-scale retrofit project.

The retro-commissioning process involves several steps, including a building assessment to identify areas for improvement, develop a plan to address those areas, implement the improvement works, and ongoing monitoring and verification to ensure the desired results. The process may involve building automation, lighting, HVAC, and other building system upgrades.

The benefits of retro-commissioning can reduce energy consumption and costs, improve indoor air quality, increase occupant comfort, and extend equipment life. In addition, retro-commissioning can help building owners and managers comply with local energy codes and regulations and achieve sustainability goals.



### 3.1. Terminology

The APEC member economies have different terminologies representing commissioning or retro-commission-related processes. This section shortlists some terminologies used in APEC member economies with similar objectives or processes adopted in this project. Table 3-1 summarises these terminologies.

Table 3-1. Summary table of terminology

Terminology	APEC member economies
Existing Building	
RCx	This project
Existing building commissioning	China <sup>(9)(14)</sup> ; United States <sup>(16)</sup>
Retro-commissioning	Australia <sup>(10)</sup> ; Canada <sup>(11)</sup> ; China <sup>(9)(14)</sup> ; Hong Kong, China <sup>(8)</sup> ; Japan <sup>(17)</sup> ; Singapore <sup>(12)</sup> ; Chinese Taipei <sup>(13)</sup> ; United States <sup>(1)</sup>
Building tuning	Australia <sup>(20)</sup> ; United States <sup>(2)</sup>
Continuous commissioning	Japan <sup>(17)</sup> ; Chinese Taipei <sup>(13)</sup> ; United States <sup>(15)</sup>
Ongoing commissioning	China <sup>(9)(14)</sup> ; United States <sup>(1)</sup>
Re-commissioning	Australia <sup>(10)</sup> ; Canada <sup>(11)</sup> ; China <sup>(9)(14)</sup> ; Chinese Taipei <sup>(13)</sup> ; United States <sup>(1)</sup>

The terms Existing Building Commissioning, Retro-commissioning (RCx), Building Tuning and Continuous Commissioning involves verification, optimisation, and analysis of existing equipment to identify efficiency and cost savings, which are similar.

Ongoing Commissioning is a continuous process that helps monitor and ensure effective and efficient building performance over its lifecycle <sup>(16)</sup>. Energy use, benchmarking, conformance to and continuous revision of the current facility requirements, automated fault detection and diagnostics, and training are all key parts of the ongoing commissioning process.

Re-commissioning, it is the commissioning of existing buildings and systems that have already gone through the commissioning <sup>(1)(3)</sup> or retro-commissioning <sup>(11)</sup> process. The building will become less efficient over time and increase the overall operating expenses. Hence re-commissioning aims to bring a building back to the original design criteria, maintain top levels of building performance, and identify new improvement

opportunities. This process is for operational buildings needing minor repairs, replacements, and resets.

The building operating and maintenance systems are examined and cleaned as needed during the commissioning process, parts may be fixed or replaced, and systems reset as if they are being installed new. This can provide the opportunity to strategically and effectively revitalize an older building. It allows a continuous building operation without losing comfort or energy efficiency.

Moreover, some terminologies used in the APEC member economies consist of “commissioning” but for new buildings, which are not the focus of this study. As summarised in Table 3-2, the terms Commissioning, New Construction Commissioning, Building Commissioning and Initial Commissioning have similar meanings, i.e. the process involves commissioning new buildings and newly installed equipment for proper operation. The record of the results is an essential reference during subsequent recommissioning<sup>(17)</sup>.

Table 3-2. Summary table of terminology

Terminology	APEC member economies
New Building	
Commissioning	Canada <sup>(11)</sup> ; China <sup>(9)(14)</sup> ; Hong Kong, China; Singapore <sup>(12)</sup> ; Chinese Taipei <sup>(13)</sup> ; United States <sup>(1)</sup>
New construction commissioning	United States <sup>(1)</sup>
Building commissioning	Australia <sup>(5)</sup> ; China <sup>(9)(14)</sup> ; United States <sup>(1)</sup>
Initial commissioning	Japan <sup>(17)</sup>

### **3.2. Summary of processes of RCx**

Retro-commissioning (RCx) is a process that involves evaluating and optimizing the performance of building services and even the building envelope of existing buildings to improve their energy efficiency, indoor air quality, and overall comfort.

Here is an overview of how retro-commissioning works:

- (i) **Benchmarking:** The first step is to benchmark the building's energy usage and performance. This stage involves gathering data on the building's energy consumption, indoor air quality, and other key performance metrics.
- (ii) **Assessment:** A comprehensive assessment of the building systems, including HVAC, lighting and controls, will be conducted. The opportunities to optimize performance, as well as energy and cost savings, will be identified. In some cases, recommendations for capital improvements may result in the assessment. They will be outside the scope of the retro-commissioning work.
- (iii) **Analysis:** The assessment team will use the data and information gathered during the assessment to analyze the building's systems and identify opportunities for improvement. The stage may involve identifying equipment not operating as efficiently as it should be, fixing leaks or other issues, or upgrading to more energy-efficient equipment.
- (iv) **Implementation:** After the analysis, the assessment team will develop a plan to implement the recommended improvements. This stage may involve changing the building's systems, such as adjusting heating and cooling settings, upgrading equipment, or installing new controls.
- (v) **Monitoring:** After the improvements have been implemented, the assessment team will monitor the building's performance to ensure that the changes have led to the desired outcomes. They may also train building operators and occupants and help them maintain the building's new level of performance. This hand-off may be a transition to Ongoing Commissioning.

For items (i), (ii), (iii) and (v), the works shall be mainly responsible by the RCx services providers, while for the item (iv) shall be decided by the building owner. Therefore, RCx is a process that requires different parties to collaborate and implement.

### 3.3. Benefit of RCx

Retro-commissioning can provide a range of benefits beyond energy efficiency that can help to improve the overall performance, comfort and safety of a building. Details are below.

- (i) **Improved energy efficiency:** Retro-commissioning involves comprehensively evaluating of a building's systems and equipment to identify inefficiencies, faults, and operational issues. These issues include malfunctioning equipment, poor control sequences, and outdated systems. By identifying energy-saving opportunities and fixing the malfunctioning or poor-performance parts, retro-commissioning can improve energy efficiency. Retro-commissioning involves ongoing monitoring and optimization of a building's performance to ensure that energy savings are maintained over time and even during low-load periods.  
**Improved Indoor Air Quality:** Retro-commissioning can identify and address issues with ventilation, air distribution, and humidity control, which can all have a significant impact on indoor air quality. By improving these factors, retro-commissioning can create a more comfortable and healthy indoor environment for building occupants.
- (ii) **Extended Equipment Life:** By identifying and addressing issues with equipment that may be causing it to work harder than necessary, retro-commissioning can help to extend the equipment life, reduce maintenance costs and avoid premature replacement of equipment.
- (iii) **Increased Occupant Comfort:** Retro-commissioning can identify and address issues with temperature control, lighting, and other factors impacting occupant comfort. Retro-commissioning can improve occupant satisfaction and productivity by creating a more comfortable indoor environment.
- (iv) **Compliance with Building Codes and Standards:** Retro-commissioning can help to ensure that a building complies with current building codes and standards. This helps to avoid penalties or fines for non-compliance and ensures the building is safe and functional.
- (v) **Improved Resilience:** Retro-commissioning can also help to improve a building's resilience to power outages and other disruptions by identifying backup power sources and other measures that can help to maintain critical building functions during an emergency.

## 4. RCx development in APEC Region

The Asia-Pacific Economic Cooperation (APEC) region has actively promoted retro-commissioning (RCx) to improve energy efficiency in buildings. APEC has recognized that buildings account for a significant portion of energy consumption and greenhouse gas emissions in the region and that RCx can help to address these issues. Several APEC member economies have also developed their own RCx programs. The details are studied and summarised to (i) Initiatives and regulations related to RCx, (ii) Guidelines, (iii) Training and (iv) Funding and Tools for promoting RCx.

### 4.1. Australia

#### 4.1.1. Initiatives and regulations related to RCx

- (i) *Energy Efficiency Guidance of Building Energy Efficiency Certificate (BEEC) (2010)*  
Australia's Commercial Building Disclosure (CBD) program was launched in 2010 and fully implemented in 2011. It is a government initiative that aims to improve the energy efficiency of commercial buildings by providing information to prospective buyers and tenants about a building's energy efficiency performance. Based on the Building Energy Efficiency Disclosure Act 2010, the CBD program requires owners of certain commercial buildings to obtain and disclose a Building Energy Efficiency Certificate (BEEC)<sup>(67)</sup> before they can be sold, leased or subleased. In the Energy Efficiency Guidance of Building Energy Efficiency Certificate (BEEC), the suggested works for improving the energy efficiency of buildings' systems are similar to the process of RCx in this study.

#### 4.1.2. Guidelines

- (i) *Greening Your Building: A Toolkit for Improving Asset Performance (2007)*  
Greening Your Building Toolkit <sup>(22)</sup> is a state-wide guideline of Melbourne launched in 2007. This guideline provides green building measures, including retro-commissioning (named "Re-commissioning – tuning"). From the guideline, commissioning is the process of testing and providing the building services meet the specified performance criteria while re-commissioning will ensure that each system meets the current requirements. The guideline also reported the benefits, risks, process and estimated cost of re-commissioning.

(ii) *AIRAH Design Application manual DA27 Building Commissioning (2011)*

The Design Application Manual DA27 for building commissioning <sup>(73)</sup> was published by the Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) in 2011 and is an industry-standard reference in Australia. Section 9 of this manual is about retro-commissioning.

(iii) *HVAC factsheet - Commissioning and building tuning (2013)*

The Department of the Environment and Energy of the Government of Australia published the “HVAC factsheet - Commissioning and building tuning” <sup>(21)</sup> in 2013. It recommends conducting building tuning (same as RCx in this study) every 10 to 15 years. By carrying out surveys and diagnostics, alterations and improvements, testing and verification, the building tuning is expected to identify and remove barriers to optimum building performance. Besides post-equipment replacement, a seasonal basis building tuning for continuously optimising the building’s performance is recommended from the factsheet for ensuring the occupancy needs are met most energy-efficiently.

(iv) *Handbook: Upgrading existing buildings (2016 and 2020)*

The “Handbook: Upgrading existing buildings” <sup>(19)</sup> is a supporting document for guiding the user to apply the requirement of the National Construction Code (NCC) <sup>(18)</sup> in a building renovation with five steps. The five steps are similar to the RCx of this study in nature, as summarised below.

- (a) Collecting related documentation from National Australian Built Environment Rating System (NABERS) and Commercial Building Disclosure Scheme;
- (b) Undertaking an on-site inspection to identify enhancement opportunities;
- (c) Comparing expected performance to identify potential deficiencies;
- (d) Classifying potential deficiency as an actual deficiency or not; and
- (e) Alleviating actual deficiencies

(v) *SA TS 5342:2021, Building Commissioning (2021)*

In 2021 Standards Australia published a technical specification for building commissioning <sup>(74)</sup> that involves works to building services such as HVAC&R, electrical, fire protection, hydraulics, architectural automated building elements and information technology that supports smart buildings, so as to provide an integrated whole-of-building process of commissioning.

(vi) *National Australian Built Environment Rating System - Energy efficiency in commercial buildings (2022)*

National Australian Built Environment Rating System (NABERS) is a voluntary rating system for assessing the environmental performance of a building and identifying areas for cost savings and future improvements. The guide on the “Energy efficiency in commercial buildings”<sup>(20)</sup> of NABERS is published in May 2022. It suggests that facility managers, operations teams and their services contractors review the NABERS Energy ratings and ensure the building is well-tuned. The guide recommends building tuning (same as RCx in this study) as a process with ongoing optimisation of start and stops schedules, set points, calibration of economy-cycle free cooling and equipment scheduling.

#### 4.1.3. *Training*

(i) *AIRAH Training: Building Tuning*

The Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH) provide Building Tuning Online Courses<sup>(23)</sup> to teach advanced building tuning techniques for improving energy efficiency and thermal comfort in buildings. The target participants are consultants, contractors and facility managers. The courses cover the benefits of building tuning and details of the four phases of the RCx process. Several technical papers related to building tuning are shared on AIRAH's website.

#### 4.1.4. *Activities for promoting RCx*

(i) *Funding - Environmental Upgrade Finance (EUF)*

Environmental Upgrade Finance (EUF)<sup>(68)</sup> is a state-level financing mechanism in the Victoria State of Australia. The EUF provides low-cost, long-term loans to improve the environmental performance of a building, such as adopting renewable energy generation, improving energy or water efficiency, waste reduction and climate change adaptation. For energy efficiency improvement, retro-commissioning is one means to support the advancement, and thus, related projects can apply for the EUF.

(ii) *Funding - Sustainable Australia Fund*

Sustainable Melbourne Fund<sup>(24)</sup> is a program for funding building tuning-related activities in Melbourne. This funding program is a state program carried out by Melbourne City Council in 2002. The funding supported the projects to establish

a track record of integrating energy efficiency, renewable energy and sustainability into the built environment. This created a new form of finance “Environmental Upgrade Finance” in Melbourne which was tailor-made to overcome barriers during environmental upgrades, such as business cash flow and the gap between the landlords and tenants. Similar forms of finance occurred in New South Wales and South Australia in 2010. Eventually, it was expanded to the whole economy of Australia in 2019 and named the Sustainable Australia Fund <sup>(69)</sup>.

## 4.2. Canada

### 4.2.1. Initiatives and regulations related to RCx

#### (i) *Recommissioning for existing buildings for Building Optimization* <sup>(25)</sup>

The Natural Resources Canada (NRCan) of the Government of Canada promotes that buildings’ systems shall be optimized for reducing energy and maintenance costs, ensuring occupant comfort and good indoor air quality. NRCan introduced several terms related to building optimization in Canada, i.e. “commissioning” for new buildings, “recommissioning” for existing buildings and “ongoing commissioning” for applying a permanent manner to an existing building. A 5 to 15 per cent energy saving with around a three-year payback period is expected to be achieved by recommissioning.

#### (ii) *Tuning Up: A Framework for Existing Building Commissioning* (2021)

“Tuning Up: A Framework for Existing Building Commissioning” <sup>(26)</sup> was developed by the Existing Building Commissioning (EBCx) Working Group and was launched in 2021. EBCx is a broad term that includes ongoing commissioning, recommissioning, and retro-commissioning. The framework aims to broaden awareness and help identify improvement opportunities for policymakers and senior management levels of stakeholders. There are five pillars of key actions for conducting EBCx – Building Capacity, Expanding the Evidence Base, Identifying and Developing Tools, Integrating EBCx into Programs and Policies, and Creating Awareness and Common Understanding. The target building types are commercial, institutional and multi-unit residential buildings.

### 4.2.2. Guidelines



(i) *Recommissioning Guide for Building Owners and Managers (2008)*

The “Recommissioning Guide for Building Owners and Managers”<sup>(27)</sup> (the “RCx Guide”) was published by Natural Resources Canada (NRCan) from the “A Retrocommissioning Guide for Building Owners” (the “US-EPA Guide”), which was developed by Portland Energy Conservation, Inc. (PECI) with funding from the U.S. Environmental Protection Agency. This RCx Guide aims to assist building owners and managers in adopting recommissioning to reduce expenses and increase revenue through improved building operations. Also, the RCx Guide provides expectations regarding the process and outcomes of recommissioning as guidance.

(ii) *Efficient Heating, Ventilation and Air conditioning (HVAC) Operation during a Pandemic: Self-evaluation Tool and Guide (2021)*

“Efficient Heating, Ventilation and Air Conditioning (HVAC) Operation during a Pandemic: Self-evaluation Tool and Guide”<sup>(70)</sup> is a voluntary guide published by Natural Resources Canada in 2021. The guide highlights key areas and best practices for efficient HVAC operation during the pandemic and allows the operators to respond to the new standard more confidently.

### 4.2.3. Training

(i) *Advanced Course on Existing Building Commissioning (EBCx)*

The CanmetENERGY and the Office of Energy Efficiency (OEE) of NRCan developed a 3.5-day advanced RCx course<sup>(28)</sup>. It is run by the Canadian Institute for Energy Training for engineers and technicians. The course includes all the stages (five in total) of the RCx process – planning, investigation, implementation, hand-over and monitoring. It covers systems of power plants, pumping systems, HVAC systems, and monitoring and control systems. The course covers persistence strategies for facility operating staff and third-party recommissioning providers to maintain the benefits of the process over the life of a building.

### 4.2.4. Activities for promoting RCx

(i) *Funding - Community building recommissioning grant (2021)*

The “Community building recommissioning grant”<sup>(29)</sup> is a program of the Federation of Canadian Municipalities (FCM). A grant will be offered to support projects related to building commissioning and building retro-commissioning at community buildings owned by government or not-for-profit. The eligible

buildings must primarily used for athletic, recreational, cultural and community programs or services to the local community.

(ii) *Tools to conduct RCx project*

CanmetENERGY provides several resources for stakeholders to properly conduct an RCx project, especially for institutional and commercial buildings. The resources include Recommissioning (RCx) Pre-Screening Tool <sup>(30)</sup>, Benchmarking Tool <sup>(31)</sup> and a Recommissioning Data Collection Form <sup>(32)</sup>. These resources help evaluate the improvement potential during the planning stage.

### **4.3. Hong Kong, China**

#### *4.3.1. Initiatives and regulations related to RCx*

(i) *Climate Action Plan 2030+ and 2050 (2017 and 2021)*

Further to the publication of the Energy Saving Plan for Hong Kong, China (HKC)'s Built Environment 2015~2025+ in May 2015 <sup>(33)</sup>, the then Environment Bureau published HKC's Climate Action Plan 2030+ and 2050 <sup>(34)</sup> in January 2017 and October 2021, respectively, for setting out the decarbonisation strategies of HKC. The building is one of the major energy consumption sectors in HKC. Retro-commissioning (RCx) is a systematic process to periodically check an existing building's performance to identify operational improvements that can save energy and thus lower energy bills and improve the indoor environment. RCx is quoted in the plans as a measure recognised for energy saving in existing buildings, with RCx to timely check the energy performance of an existing building to identify energy saving potentials for operational improvement.

#### *4.3.2. Guidelines*

(i) *Technical Guidelines on Retro-commissioning (2017, 2018)*

The Electrical and Mechanical Services Department (EMSD) of the Government of HKC launched the Technical Guidelines on Retro-commissioning (TG-RCx) <sup>(35)</sup> in 2017 and updated it in 2018. The technical guideline provides essential and clear procedural guidance on RCx. The TG-RCx advises four stages of the RCx – Planning, Investigation, Implementation and Ongoing Commissioning. In the planning stage, operational data on energy-consuming equipment/systems will be collected, followed by on-site measurement testing and data analysis to come up

with proposed Energy Saving Opportunities (ESOs). Through the implementation of the ESOs, the operational performance of building systems, building energy efficiency and occupant comfort levels will be improved.

(ii) *BSOMES's Strengthening the Technical Capability and Regional Collaboration in Implementing RCx in Buildings (2021)*

In 2021, the Building Services Operation and Maintenance Executives Society (BSOMES) launched the “Strengthening the Technical Capability and Regional Collaboration in Implementing RCx in Buildings”<sup>(36)</sup>. The publication includes a guidebook and ten videos with the knowledge and practical skills in implementing RCx. Moreover, this guidebook mentions the importance of sub-metering in different energy-consuming equipment/systems for data collection. The collected data will apply to the computerized energy simulation tools for simulating energy models based on the existing system information, operation schedule and electricity bills. Different energy modelling strategies may allow further enhancement of the RCx process.

### 4.3.3. Training

(i) *HKGBC's RCx Training and Registration Scheme (2019)*

A RCx Training and Registration Scheme<sup>(37)</sup> was launched by the Hong Kong Green Building Council (HKGBC) with the support of the EMSD and other professional institutions. The objective of the programme is to build the capacity of RCx within the industry. Training courses are organised for local engineers and stakeholders to fulfil the training requirement of the registration scheme. Abiding by the principle of preparing “designated workers for designated skills”, HKGBC's RCx Training and Registration Scheme offer individual courses with specific focuses for different tiers of practitioners, including RCx Practitioner (Level 1), RCx Practitioner (Level 2) and RCx Professional.

(ii) *RCx seminars (2017)*

Since 2017, several seminars for building services operation and maintenance engineers to share their knowledge, skills and the latest development on RCx implementation. The seminars enhance participants' understanding of the challenges and opportunities for regional collaboration, thereby uplifting the service standards and competitiveness of the building sector.

*(iii) Green Schools 2.0 for Retro-commissioning (2020-2021)*

A series of seminars and workshops, under the programme “Green Schools 2.0 for Retro-commissioning”<sup>(38)</sup> to introduce RCx to different levels of stakeholders. The participants include, for example, the management and operation levels of facility management teams of premises, the project development teams and services providers.

*(iv) ACT-Shop Programme (2016)*

ACT-Shop Programme was launched in 2016. The programme encourages existing building practitioners to implement knowledge-based energy management and retro-commissioning practices at their buildings. “ACT-Shop” is designed as a platform for a group of participating companies to work step-by-step with experienced facilitators to carry out RCx for their buildings; and to build up their in-house competency in terms of data, knowledge, and technology etc. on retro and re-commissioning practices, preparing for major retrofits and the mandatory energy audit. Moreover, the “ACT-Shop” provides a collaborative platform for the private sector to work as peers to develop standardised alternative methodologies for harnessing comprehensive data instead of using resource-demanding metering systems. Four batches of pilot cases with 24 commercial buildings participated in the programme.

*(v) RCx Charter Programme (2021) and associated training*

The power companies in HKC launched an RCx Charter Programme in 2021 to encourage different building sectors to implement RCx. Alongside the Charter Programme, an Advanced Training Course for training the energy management teams with basic RCx knowledge to further upgrade their skills. The programme aimed to help businesses to achieve low-carbon transformation cost-effectively.

#### *4.3.4. Activities for promoting RCx*

*(i) Project - RCx pilot study in government buildings (2016)*

In 2016, EMSD commenced an RCx pilot study in government buildings to evaluate how RCx is practically applied to buildings. Upon implementing ESOs identified by RCx process, the annual electricity saving was about 5% of the total building electricity consumption in 2014 to 2015.

(ii) *Memorandum of Cooperation on RCx of Buildings in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) (2018)*

The EMSD of the Government of HKC signed a memorandum of co-operation (MOC) with the Hong Kong Green Building Council, and 5 other institutes and universities including the Building Services Operation and Maintenance Executives Society, the Macao Institution of Electrical and Mechanical Engineers, the City Air-conditioning Energy Conservation and Control of Guangdong Project Technology Research Exploitation Centre of the South China University of Technology, the Building Energy Conservation Research Centre of Tsinghua University and the Shanghai Research Institute of Building Sciences to promote the development and application of RCx of buildings in the Guangdong-Hong Kong-Macao Greater Bay Area.

(iii) *Subsidies by utilities of Hong Kong, China (2018, 2019)*

The two power companies provided subsidies for their customers to conduct energy-saving improvement works. In 2018, a subsidy scheme named “Eco-Building Fund” was launched by one of the power companies to provide subsidies for energy-saving improvement works to the communal areas of shopping malls, residential, commercial and industrial buildings. The improvement works include replacing air-conditioning and lighting systems, conducting retro-commissioning projects, and implementing smart technologies to increase energy efficiency and reduce electricity expenses. In 2019, a similar subsidy scheme named “Smart Power Building Fund” was launched by the other power company for its customers.

(iv) *RCx On-line Resources Centre (2019)*

EMSD has established a RCx Resources Centre <sup>(72)</sup> in 2019 to provide a one-stop platform for practitioners to obtain information on RCx and related activities. The resources centre contains the latest local RCx guidelines, common RCx technical tips with training materials, latest RCx seminars and trainings. The goal of the resource centre is to help building owners and operators improve the energy efficiency and sustainability of their buildings, reduce operating costs, and contribute to the overall environmental goals of the region.

(v) *Campaign – Energy Saving Championship Scheme (2019)*

The Energy Saving Championship Scheme was launched in 2019 to encourage more organisations from different sectors to take the lead in a plan for and implement RCx to enhance the energy efficiency of existing buildings and share their experience and I&T ideas in identifying and implementing the energy-saving

opportunities (ESOs) during RCx works. Also, the Scheme was to encourage youth to express their innovative and imaginative ideas on EE&C and/or RE initiatives or technology.

*(vi) Campaign - Wise Save @ RCx Competition (2022)*

The “Wise Save @ RCx Competition” was a promotional activity launched in 2022 to encourage the stakeholders to enhance the energy efficiency of existing buildings, striving towards the goal of carbon neutrality, through the application of retro-commissioning RCx and Innovation and Technology (I&T). The target participants were building owners, property management companies, facility management companies and RCx services providers.

## **4.4. Japan**

### *4.4.1. Initiatives and regulations related to RCx*

*(i) Global Warming Countermeasure Plan (translated from “地球温暖化対策計画”) (2016)*

The Global Warming Countermeasure Plan <sup>(39)</sup> was launched in 2016 by the Ministry of the Environment of Japan with reported the importance and relationship of existing buildings with energy saving and greenhouse gas emission reduction. It requires existing buildings to comply with energy conservation standards and carry out energy-saving measures. The suggested actions for different stakeholders are detailed as follows:

- Owners, etc.: Refurbishment to energy-saving buildings, etc.
- Building sales and leasing businesses: Indication of building energy consumption performance
- Manufacturers of heat insulation materials: Improving the performance of heat insulation materials to prevent heat loss

*(ii) Building Energy Conservation Law (revised in 2022)*

The building sector accounts for about 30% of Japan's energy consumption. In 2022, the Building Energy Conservation Law was revised to achieve carbon neutrality by 2050 and a 46% reduction in greenhouse gas emissions by 2030 (as compared to 2013). Drastic strengthening of measures for further improving the energy-saving performance of buildings are launched. Building owners shall make

efforts to improve performance. Also, it compulsorily displays the energy consumption performance of the buildings when they are going to be sold or rented.

#### 4.4.2. Guidelines

- (i) *Commissioning Process of Building Services Systems (translated from 建築設備の性能検証過程指針) (2005)*

In November 2005, the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) launched the guideline of The Commissioning Process of Building Services Systems (SHASE-G-0006-2004). The guideline is not directly related to retro-commissioning. Still, it explains the actions related to commissioning during the building life cycle from design, elaboration, construction and post-acceptance to operation phases. Therefore, the industry can refer to this guideline for ongoing commissioning actions.

- (ii) *Commissioning Manual of Building Services Systems (translated from 建築設備コミッショニングマニュアル) (2010)*

The Building Services Commissioning Association (BSCA) is an organisation in Japan to Establish practical guidelines and tools, provide training and seminars and propose qualification related to retro-commissioning. The BSCA launched the Commissioning Manual of Building Services Systems (Cx Manual)<sup>(40)</sup> in 2010 and revised it in 2016. There are six chapters in the manual covering different types of commissioning processes, including the outline of commission works (chapter 2), commissioning of existing buildings (chapter 4) and tool utilisation in commissioning (chapter 6).

#### 4.4.3. Training

- (i) *Commissioning Professional Engineer (CxPE) (2010)*

The BSCA provides the training “Commissioning Professional Engineer (CxPE)”<sup>(41)</sup> for engineers who manage the commissioning process. The CxPE training is 18 hours duration. The training programme aims to let the trainees understand the commissioning process and possess the technical knowledge required to manage the commissioning processes. They must understand the construction process and demonstrate the ability to communicate with related parties, such as the designers and contractors. They need to demonstrate the ability to offer appropriate advice within the scope of their expertise when problems arise in commissioning and to demonstrate ethical values that enable them to judge issues fairly.

(ii) *Commissioning Technical Engineer (CxTE) (2013)*

The BSCA provides the training “Commissioning Technical Engineer (CxTE)”<sup>(42)</sup> for engineers who can carry out actual tests such as functional performance testing and operational optimisation tests. The CxTEs are categorised into two areas based on their field of specialisation and the scope of expertise:

- CxTE-A: Engineers who demonstrate excellence in measurement, data analysis, and processing
- CxTE-B: Engineers who demonstrate excellence in Cx tools and simulation

The CxTE training programme aims to enable the trainees to follow the CxPE instructions when conducting commissioning tasks. The training includes measurement and analytical skills, knowledge in controlling trial and automatic operation, actions in inspection work on-site, handling data processing and using simulation tools, failure detection and diagnosis, optimising systems, and tuning the building services systems to an optimum state.

#### *4.4.4. Activities for promoting RCx*

(i) *Tool - Commissioning Tool Library (2008)*

The BSCA provides a webpage-based sharing platform, “Commissioning Tool Library”<sup>(43)</sup>, to share the tools developed by the SHASE Commissioning Committee. The tools cover different phases in commissioning, including Cx Process Management, Data Processing, Simulation Creation, Design Verification, Field Measurements, Evaluation Analysis, Fault Detection and Performance Optimisation.

## **4.5. United States**

### *4.5.1. Initiatives and regulations related to RCx*

(i) *US Code 42 U.S.C. § 8253(sf)(3)(A) - Recommissioning and Retro-commissioning*

The US Code 42 U.S.C. § 8253(f)(3)(A)<sup>(44)</sup> is a requirement for energy and water evaluations and commissioning. It requires energy/water audits periodically for at least 25% of “covered” buildings, and RCx is one of the defined methods for meeting this requirement.



(ii) *Building Re-tuning*

Under the Federal Energy Management Program launched by the Department of Energy of United States, re-tuning <sup>(71)</sup> is introduced as a facility optimization process. The re-tuning can bring 5 - 25% energy saving in the government building with building automatic control. The re-tuning includes steps of basic building information collection, trend-data collection and analysis, building walks down, identifying and implementing re-tuning actions, report findings and recommended actions and implementations, analysis savings, and continued use of re-tuning in operation and maintenance. The steps are principally the same as the retro-commissioning of this study.

(iii) *City-level initiatives*

Several cities in United States recognised and introduced RCx for achieving building energy efficiency. Here are some examples,

- *Local Law 87 (LL87) of the New York City (2009)*

To align with the Greener, Greater Building Plan (GGBP), New York City launched a city-based regulation named “Local Law 87 (LL87)” <sup>(45)</sup> in 2009, which is about the Energy Audits and Retro-Commissioning (Retro-Cx) to commercial, mixed-use and residential buildings. The LL87 is a city-based policy that requires a large building to carry out retro-commissioning every ten years. LL87 mandates an energy efficiency report (EER) to be submitted by owners of buildings with over 50,000 gross square feet. Energy audits and Retro-Cx are required for the base building system of a covered building before filing an energy efficiency report.

- *Existing Commercial Buildings Energy Performance Ordinance of San Francisco (2011)*

San Francisco’s Existing Commercial Buildings Energy Performance Ordinance (ECB ordinance) <sup>(75)</sup> launched in 2011. Referring to the ECB ordinance, building owners can select retro-commissioning as an alternative to energy auditing. The ECB ordinance is set for moving towards the target to reduce total energy consumption in non-residential buildings by 2.5% per year, achieving a total reduction of 50% by 2030 below 1990 levels, aligning with the City’s 2013 Climate Action Strategy Update and the State of California’s goal of achieving zero net energy in 50% of existing commercial buildings by 2030.

- *Commercial Energy Efficiency Ordinance of Atlanta (2015)*  
Atlanta's Commercial Energy Efficiency Ordinance <sup>(46)</sup> (15-O-1101) is a city-based policy published in 2015 by the Mayor's Office of Sustainability of the City of Atlanta. The ordinance aligns with Atlanta's sustainability initiative "Power to Change" to reduce commercial energy consumption by 20% by 2020. Retro-commissioning is required to be conducted every ten years. The retro-commissioning process shall be carried out by authorized Retro-commissioning professionals.
  
- *Building Energy & Water Efficiency Strategy of Orlando (2016)*  
Building Energy and Water Efficiency Strategy (BEWES) <sup>(76)</sup> was launched in 2016 by the Orlando City Council and is a key strategy identified in the Green Works Orlando Community Action Plan. BEWES is a policy focused on tracking the energy and water output of our largest buildings. It requires the building operators to conduct energy audits or retro-commissioning for certain conditions.
  
- *Building Tune-Ups Ordinance of Seattle (2017)*  
Seattle's Building Tune-Ups Ordinance <sup>(47)</sup> is a city-based policy published by the City of Seattle in 2017. This ordinance aligns with Seattle's Climate Action Plan (2013) <sup>(48)</sup>, which aims to achieve carbon neutrality by ensuring buildings not wasting energy and water. It required that all buildings need to be tuned regularly to keep them running as efficiently as possible, similar to cars and bikes. Tune-ups are similar to retro-commissioning but with less-rigorous documentation and functional testing. Building Tune-Ups involves assessing and implementing operational and maintenance improvements to achieve energy and water efficiency and is to be conducted by a qualified Tune-Up Specialist.

#### 4.5.2. Guidelines

##### (i) *Commissioning for Federal Facilities (2006)*

The Federal Energy Management Program (FEMP) was launched by the Office of Energy Efficiency and Renewable Energy from the Department of Energy in United States. FEMP is to facilitate the implementation of sound and cost-effective energy management and investment practices in government buildings for enhancing energy security and environmental stewardship.

A guideline named “Commissioning for Federal Facilities”<sup>(50)</sup> is launched under the FEMP. This guideline is a practical guide to building commissioning, recommissioning, retro-commissioning and continuous commissioning. There are four types of commissioning defined in the guideline with corresponding methodologies. The four types of commissioning are listed below:

1. Commissioning: It is an application for new construction or major renovation projects. Commissioning shall be implemented through all phases of the construction project.
2. Retro-commissioning: It is a process for older facilities that have never been through a commissioning process and have experienced several equipment failures.
3. Recommissioning: It is a process to tune up buildings that have already been commissioned. Recommissioning is a process to bring the building services systems back to their original design intent and operating energy efficiently. This type of commissioning is similar to the RCx as defined in this study.
4. Continuous Commissioning: It is a process for facilities with building automation systems (BAS), advanced metering systems, and advanced O&M organisations. Continuous Commissioning shall apply to buildings that are large, complex and have a high energy cost.

*(ii) Operations & Maintenance Best Practices (2010)*

The Operations & Maintenance Best Practices (Release 3.0)<sup>(51)</sup> was launched in 2010 under the Federal Energy Management Program (FEMP) by the Office of Energy Efficiency and Renewable Energy from the Department of Energy in United States. Chapter 7 of this guideline is titled “Commissioning Existing Buildings”. Besides the four types of commissioning as mentioned in the guideline “Commissioning for Federal Facilities”, Value Re-commissioning (VCx) is mentioned. Value recommissioning (VCx) is the lowest-cost option that focuses on the most common opportunities that typically carry the shortest payback periods.

*(iii) Energy Audits and Retro-Commissioning: State and Local Policy Design Guide and Sample Policy Language (2013)*

A guide named “Energy Audits and Retro-Commissioning: State and Local Policy Design Guide and Sample Policy Language”<sup>(49)</sup> is published by the State and Local Energy Efficiency Action Network’s (SEE Action) Existing Commercial Buildings Working Group under the contract with the Department of Energy. This guide provides information to help policymakers better understand the value of energy audits and retro-commissioning. This guide assists policymakers in planning the

applicable policies to drive energy audits and retro-commissioning activity among public and private sector buildings for achieving cost-effective energy efficiency measures by 2020.

(iv) *ASHRAE Guideline 0.2 (2015)*

ASHRAE Guideline 0.2<sup>(77)</sup> is titled Commissioning Process for Existing Building Systems and Assemblies and launched by ASHRAE in 2015. This guideline provides a step-by-step process to owners and facility managers in 10 sections for ensuring optimum systems performance.

(v) *ACG Commissioning Guideline*

The ABC Commissioning Group (ACG)<sup>(52)</sup> is a non-profit association that provides training and guidelines. The ACG Commissioning Guideline is for building owners, design professionals and commissioning service providers with a comprehensive description of the commissioning process. It includes sample forms, specifications, checklists and other commissioning documentation. The highlight of the ACG Commissioning Guideline is as below:

- Provides information on the ACG commissioning certification program;
- Provides a detailed methodology for both comprehensive and construction HVAC commissioning;
- Covers commissioning in both new construction and existing buildings;
- Covers HVAC systems typically found in commercial and institutional buildings;
- Provides standards for proper documentation and reporting, with sample forms; and
- Defines the roles and responsibilities of all commissioning team members.

(vi) *BCxP Study Guide*

The Building Commissioning Professional (BCxP) Study Guide<sup>(53)</sup> is a guideline provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). The Study Guide provides a self-learning framework and tools for commissioning professionals. It aims to help improve their knowledge and skills in building commissioning works.

(vii) *Ongoing Commissioning Best Practices*

The Building Commissioning Association (BCxA)<sup>(54)</sup> aims to achieve high professional standards while allowing diverse and creative approaches to building commissioning that benefit the profession and its clients. The BCxA establishes a

governance system and develops a website for promoting building commissioning with knowledge sharing. Application samples and templates for commissioning are available from the website. There are three best practices launched by the BCxA, two for commissioning new or existing buildings, and one is named Ongoing Commissioning (OCx) Best Practices. This OCx Best Practices aims to educate the stakeholders to maintain the benchmark of standards for planning and implementing ongoing commissioning.

*(viii) RCx specification by NEBB*

The National Environmental Balancing Bureau (NEBB) is an association provides certification, guidelines (in terms of RCx specification and RCx instrument requirements) and training to promote high-performance building systems. Regarding RCx to the existing building, the phrase used by NEBB is also “Retro-commissioning”<sup>(55)</sup>. RCx in NEBB aims to provide optimal performance. The processes include strategic planning and execution, field verification, testing, analysis and documentation of facts.

*(ix) Technical Notes by the National Institute of Standards and Technology for RCx-related knowledge sharing*

The National Institute of Standards and Technology (NIST) of the Department of Commerce in United States published several Technical Notes related to RCx aims to reduce the burden of implementing RCx-related works. Some of the RCx-related Technical Notes are listed below.

- The NIST Technical Notes 2024 (NIST.TN.2024) is titled “Commissioning ASHRAE high-performance sequences of operation for multiple-zone variable air volume air handling units”<sup>(62)</sup> (2019).
  - This NIST.TN.2024 shares the ASHRAE Guideline 36 “High Performance Sequences of Operation for HVAC Systems”. It can be used as a reference for operating and commissioning the air-side heating, ventilating and air-conditioning (HVAC) equipment.
- The NIST Technical Notes 2027 (NIST.TN.2027) is titled “Retro-commissioning a performing arts centre using HVAC-Cx”<sup>(63)</sup> (2019).
  - This NIST.TN.2027 is a case study about using a commissioning software (named HVAC-Cx) for the energy retro-commissioning of the Performing Arts Centre at Montgomery College in Rockville, Maryland. It is reported in this TN the benefits of employing automated tools when compared to a manual approach during the RCx process.

### 4.5.3. Training

In United States, the Better Buildings Workforce Guidelines<sup>(56)</sup> (BBWG) is a program launched by the Department of Energy. BBWG defined requirements to enable multiple organizations to deliver consistent training/certification programs for commissioning. The types of the workforce are the four key energy-related jobs: building energy auditor, building commissioning professional, energy manager and building operations professional. Regarding the building commissioning professional, four BBWG-recognised certifications, are listed below.

(i) *CxA by ACG*

The ACG is a non-profit association. It serves as an independent third-party commissioning professional in United States. The training and certification program is called the “CxA program”. The certification is named CxA<sup>(57)</sup>.

(ii) *BCxP by ASHRAE*

The ASHRAE launched a certification program named the Building Commissioning Professional (BCxP) certification program<sup>(58)</sup>. The building commissioning professionals are self-learnt with the BCxP Study Guide<sup>(59)</sup>.

(iii) *CCP by BCxA*

The BCxA provides a training program and certification program for building commissioning professionals. The certified professional is named CCP.

(iv) *Technical Retro-Commissioning Certification by NEBB*

The certification program of RCx by the NEBB is named the Technical Retro-Commissioning Certification. There are RCx specifications and instrumentation requirements for the workforce to reference.

### 4.5.4. Activities for promoting RCx

(i) *Campaign - Smart Energy Analytics Campaign (2016-2020)*

In United States, Better Buildings is an initiative of the Department of Energy. To align with this initiative, the Smart Energy Analytics Campaign<sup>(60)</sup> was a public-private sector partnership program executed in the year 2016-2020. The Campaign encouraged commercial building owners to use energy information systems (EIS) and fault detection and diagnostic tools (FDD) through a monitoring-based commissioning process (MBCx). The MBCx focused on the analysis of a large

amount of data continuously. By 2020, 104 campuses and enterprises joined the Smart Energy Analytics Campaign.

(ii) *Tool - Retro-commissioning data collection tool in the New York City*

The New York City Department of Buildings provides a retro-commissioning data collection tool to prepare a full Retro-Cx report.

(iii) *Partnership program - Monitoring-Based Commissioning in California*

There were pilot partnerships between California investor-owned utilities (IOUs) and their customers from 2004 to 2005 funded by California utility customers under the auspices of the California Public Utilities Commission. The California State University (CSU) and UC made one of the first proposals for such a pilot partnership with the Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), San Diego Gas and Electric Company (SDG&E), and Southern California Gas (SCG) formed the UC/CSU/IOU Energy Efficiency Partnership, which eventually dubbed monitoring-based commissioning (MBCx). The Partnership MBCx element funds the permanent upgrade of building-level energy meters and energy information systems to facilitate trending and benchmarking of building energy performance. The funding also supported the investment in training for staff. According to a research finding <sup>(78)</sup>, an energy saving of 5-15% resulted from the building projects enrolled in 2006-2008 to the program.

(iv) *Utility-funded programs related to retro-commissioning*

Utilities and other third-party energy efficiency management organisations can help governments to understand what is going on in the energy sector and energy consumption patterns across their jurisdictions. There are several programs launched in United States, some are listed below.

- *Campaign - Association of Bay Area Governments' Energy Watch program (2006-2008)*

The Association of Bay Area Governments (ABAG) Energy Watch Partnership was a partnership among local governments of the ABAG and the Pacific Gas and Electric utility, provided implementation assistance for retro-commissioning projects in government buildings and other community buildings.

- *Campaign - Retro-Commissioning Pilot Program in New Jersey (2010)*  
The Retro-Commissioning (RCx) Pilot Program <sup>(64)</sup> was introduced in 2010 and was a part of New Jersey’s SmartStart Building Program. Both a rebate incentive and free training course were provided to the parties involved in the program.
- *Funding - Existing Building Commissioning (EBCx) program of Seattle*  
The Existing Building Commissioning (EBCx) program <sup>(65)</sup> was launched by the Seattle City Light in 2021. It aligns with Seattle’s Climate Action Plan (2013). The program provides incentives for retro-commissioning (RCx) or monitoring-based commissioning (MBCx) of the building’s existing systems.

## 5. Challenges for pushing forward RCx policy

Even though retro-commissioning has been well discussed among professionals from the APEC member economies, RCx has yet to become the mainstream focus. Apart from the funding issue, four obstacles are observed, including the lack of awareness of RCx among stakeholders, the behaviour of the operation and maintenance teams, the situation of existing buildings; and the technologies and workforce required for RCx.

### (i) Lack of Awareness of RCx among Stakeholders

To promote RCx to become a mainstream consideration in building design and operation, we need to change the mindset of the building owners and practitioners. Continuously communicating the values of RCx to the industry is important. It is still common for the stakeholders of existing buildings to “comply with” regulations instead of stepping “ahead of the energy efficiency-related regulations. Moreover, many stakeholders do not fully understand that RCx is a green operation of the building instead of a new project. Substantial incentives, recognition and training will useful encourage more adoption of RCx.

### (ii) Behaviour of the Operation and Maintenance Team

Continuous commissioning of building services facilities is not a common practice because operators are used to catering for users’ satisfaction and personal requirement instead of operational performance and energy efficiency. Sometimes, even the building may equipped with an automatic control system. The control may be manually overridden if the setting cannot fulfil user requirements. Together



with conventional experience-based daily building operations, there will be difficulty in understanding the corresponding impact on system energy efficiency performance with the change of settings as per users' requirements. Moreover, the Operation and Maintenance (O&M) team usually follows the fast route or routine procedures for building operations instead of following data analysis. Therefore, there will be more work for adopting new technologies in operating this kind of building.

### **(iii) Situation of Existing Buildings**

The need for better-quality data is a big challenge for implementing RCx. This happened in three kinds of building and operation situations.

- (1) Many old existing buildings need sensors and meters for monitoring and data collection. Data and information are recorded manually on log sheets. The accuracy of this kind of data may be low and not easy for data analysis.
- (2) However, for those buildings with sensors, actuators and meters, the calibration and commissioning of devices shall be concerned. Sometimes, operators may adjust the set points according to clients' requirements or responses to complaints and ignore the performance of the overall system.
- (3) Some buildings may have automation and performance management systems (e.g. building automation system (BAS), building management system (BMS), central control and monitoring system (CCMS), etc.). However, some of the control rules of these automatic systems are similar to a timer. In some cases, insufficient data for data analysis may occur even if the buildings have installed BAS, BMS, or CCMS.

### **(iv) Technologies and Manpower required for RCx**

From a technical point of view, equipment-based data is necessary for RCx. A sufficient number of instruments, including fix-installed sensors and meters, is required for data collection. It can improve the operational standard of the O&M team on data capture and use of data by professionals. Calibration and commissioning requirements, as well as relevant standards of instruments, automatic control systems and equipment, are important to ensure appropriate data quality for use by professionals. For human resources, proper training is required to enable designers and O&M teams with the ability to strike a balance between energy saving, cost-effectiveness and building users' satisfaction. For example, the designer has to avoid having unnecessary layers to the standard construction process for RCx to optimise the investment; the O&M team can do a cost-benefit analysis to recognise the contribution of RCx in terms of building operation and

energy saving.

## 6. Best Practices for RCx implementation

After examining the RCx roadmap and development status of the APEC member economies, five best practices for RCx implementation are summarised in this section.

### (i) Initiative from the Government

The government needs to take the initiative in driving the focus on energy saving from existing buildings. With proper government directives and support, the trade and academia will be more proactive in planning and investing in the financial, technological and workforce requirements for RCx projects. A clear action plan and timetable with short and long-term energy-saving targets are critical success factors for RCx projects. The investors should prepare viable cashflow plans for successful RCx implementations, facilitating all the buildings' energy audit, modification and replacement works. Academia can research and develop new technical papers to provide knowledge support to the trade. The training institutes can design and conduct training courses for the practitioners and professionals in adapting to the new working environment with a good understanding of the energy-saving goals and related actions. And the trade can encourage their employees to join the training and become certified RCx personnel.

### (ii) Setting RCx guidelines

Besides the guidelines launched in several APEC member economies, specific international guidelines can be referenced when compiling a local RCx guide. Some of the international guidelines relevant to the RCx processes are listed below:

- Annex 47 of the International Energy Agency (IEA)
- ASHRAE Guideline 1 – 1996 – The HVAC Commissioning Process
- CIBSE Commissioning Code M: Commissioning Management
- Green Star Technical Manual – Office Design v2: MAN-2
- IEA/ECBCS/Annex40 “Commissioning of Building HVAC Systems for Improved Energy Performance”
- IEA/ECBCS/Annex47 “Cost Effective Commissioning of Existing and Low Energy Buildings”
- IEA/EBC/Annex81 “Data Driven Smart Buildings”

### **(iii) Provide capacity building trainings**

Within each RCx project, different stakeholders have different focuses and scopes of work. Capacity building and raising the industry's competence are essential. With continuous technological advancement and experience accumulation, there is an ongoing demand for capacity building trainings.

Corresponding capacity-building training is necessary to address individual needs, such as:

- Building owners need to know how commissioning will provide clear economic benefits and improve building performance. Although some case studies are readily available, there is still a strong demand for more detailed cost-benefit analysis for many other projects of diverse nature. While the topic of commissioning appears in several design/construction and facility management trade papers, it is comparatively less popular among the trade papers for the building owner communities.
- Operators should be able to commission and calibrate the instruments, automatic control devices and equipment on site. They also need to understand the various data sources and how to maintain the data quality.
- Engineering teams should know how to use data to discover operation performance issues. They must develop improvement measures after diagnostic tests using measurement and verification (M&V) approaches.
- Management executives should have good knowledge of the advantages of RCx and how to apply it to other energy conservation projects. Typical examples include the replacement with energy-efficient equipment to resume and improve the efficiency of a system; the modification of over-provided equipment or system with lower part-load performance components to enhance the quality of the overall system efficiency; the conversion to a more efficient, better performance, smart and innovative system through retrofitting plus RCx in order to increase the saving and to shorten the payback period of the investment.

### **(iv) Encourage more and diverse funding sources for RCx**

The government is one of many funding source for RCx or energy-saving activities. Power companies and professional associations are good candidates to offer financial help to go along with their ultimate interests. A collaborative environment shall be encouraged for stakeholders to collaborate to co-finance or sponsor RCx research, training and projects.

### **(v) Open resources for RCx**

It is desirable to have a single location for all the information related to RCx implementation, a central place for sharing knowledge and availabilities of funding and workforce. It could be a web portal managed by an association, which collects and shares technical guides and tools, posts upcoming training events and ongoing funding opportunities, lists accredited professionals and service providers available, and exhibits outstanding case studies for knowledge exchange.

## **7. Framework for RCx implementation**

The framework of RCx implementation can be summarised into four groups of actions, i.e. (i) Target and policy; (ii) Collaboration; (iii) Technical support; and (iv) Financial support. The details of these four groups of actions are discussed in this part.

### **7.1. Target and policy**

#### *7.1.1. Setting energy efficiency targets*

APEC member economies can set energy efficiency targets for buildings in their regions. These targets can provide a goal for building owners and operators to work towards and can help to drive demand for RCx services.

#### *7.1.2. Implementing energy codes and standards*

APEC member economies can implement energy codes and standards for buildings requiring certain energy efficiency levels. These codes and standards can help to ensure that new buildings are designed and constructed to be energy-efficient and drive demand for RCx services in existing buildings.

#### *7.1.3. Developing guidelines and best practices*

APEC member economies can develop guidelines and best practices for RCx to provide building owners and operators with a roadmap for implementing RCx projects. These guidelines can include information on RCx processes, tools, and technologies, as well as case studies and success stories to demonstrate the benefits of RCx.

#### *7.1.4. Incorporating RCx into building codes and regulations*

APEC member economies can incorporate RCx into building codes and regulations to require building owners and operators to implement RCx projects. This helps ensure that RCx is considered as part of the building design and

construction process and can help to drive demand for RCx services.

#### *7.1.5. Establishing benchmarking and disclosure programs*

APEC member economies can establish benchmarking and disclosure programs for buildings to require building owners and operators to track and report on their building's energy consumption and performance. These programs can help to identify energy-saving opportunities and can help to drive demand for RCx services.

#### *7.1.6. Promoting green building certification schemes.*

APEC member economies can promote green building certification schemes, such as LEED or BREEAM, to encourage building owners and operators to implement energy-saving measures. These certification schemes can provide a framework for benchmarking and improving building energy efficiency and can help to drive demand for RCx services.

## **7.2. Collaboration**

#### *7.2.1. Encouraging public-private partnerships*

APEC member economies can encourage public-private partnerships to promote RCx in buildings. These partnerships can bring building owners and operators, government agencies, ESCOs, and other stakeholders together to identify energy-saving opportunities and implement RCx projects.

#### *7.2.2. Raising awareness*

APEC member economies can raise awareness of RCx among building owners, operators, and the general public. This can include educational campaigns, outreach efforts, and media coverage to highlight the benefits of RCx and promote energy efficiency in buildings.

#### *7.2.3. Engaging with building industry associations*

APEC member economies can engage with building industry associations to promote RCx and energy efficiency in buildings. These associations can raise awareness among their members and provide training and resources to promote RCx services. It is important to raise the image and competence of practitioners or professionals in society, with the contribution from the building industry associations.

#### *7.2.4. Fostering international cooperation*

APEC member economies can foster international cooperation on RCx to share best practices, technologies, and experiences. This can include knowledge-sharing workshops, joint research projects, and other collaborative efforts to promote RCx and improve building energy efficiency in the region.

#### *7.2.5. Establishing a regional RCx centre of excellence.*

APEC member economies can establish a regional RCx centre of excellence to promote RCx and energy efficiency in buildings in the region. The centre can provide technical assistance, training, and resources to building owners and operators, RCx service providers, and other stakeholders in the region.

### **7.3. Technical support**

#### *7.3.1. Providing technical assistance and training*

APEC member economies can provide technical assistance and training to building owners and operators to help them identify energy-saving opportunities and implement RCx projects. Also, technical assistance and training shall be provided to RCx service providers to help them improve the quality and effectiveness of their RCx services. These can include workshops, webinars, training and online resources on RCx processes, tools, and technologies, and guidance on identifying and implementing energy-saving opportunities.

#### *7.3.2. Using building energy data analytics*

APEC member economies can use building energy data analytics to identify energy-saving opportunities and prioritize RCx projects. By analyzing building energy data, building owners and operators can gain insights into how their buildings perform and identify improvement areas.

#### *7.3.3. Creating a network of RCx practitioners*

APEC member economies can create a network of RCx practitioners to share knowledge and best practices on RCx. This can include online forums, webinars, and other collaborative platforms to facilitate knowledge-sharing and collaboration among RCx practitioners in the region.

#### *7.3.4. Developing a certification program for RCx service providers*

APEC member economies can develop a certification program for RCx service providers to ensure they have the necessary skills and expertise to provide high-

quality RCx services. A certification program helps to establish standards for RCx services and enables the building owners and operators to identify qualified RCx service providers.

#### *7.3.5. Establishing pilot projects*

APEC member economies can establish pilot RCx projects to demonstrate the benefits of RCx and encourage building owners and operators to implement RCx projects. These pilot projects can serve as case studies and success stories that can be used to promote RCx and demonstrate the positive impact of energy-saving measures.

#### *7.3.6. Fostering innovation.*

APEC member economies can foster innovation in RCx and energy efficiency in buildings by investing in research and development and promoting new technologies and practices. This can include funding research on new RCx processes, tools, and technologies, as well as promoting innovative financing mechanisms and business models.

### **7.4. Financial support**

#### *7.4.1. Providing incentives for energy service companies (ESCOs)*

APEC member economies can provide incentives for ESCOs to promote RCx services. This can include financial incentives, such as grants or tax credits, to encourage ESCOs to offer RCx services and help building owners and operators implement energy-saving measures.

#### *7.4.2. Offering financial incentives*

APEC member economies can offer financial incentives, such as grants or rebates, to building owners and operators who implement RCx projects. These incentives can offset the costs of RCx projects and encourage building owners and operators to undertake energy-saving measures.

#### *7.4.3. Developing innovative financing mechanisms.*

APEC member economies can develop innovative financing mechanisms to help the building owners and operators finance RCx projects. This can include green bonds, energy performance contracting, and other financing mechanisms that provide low-cost capital to finance energy-saving measures.

## 8. Innovative technologies related to RCx

Innovative technology has shown a potential saving of 8-18% of total building energy consumption. Several factors will affect the selection of smart building technologies when conducting retro-commissioning, such as the building's systems and usage patterns, the available budget, and the desired outcomes. The technologies generally include the Internet of Things (IoT), advanced sensors, data analytics and other innovative technologies, details as below.

### (i) Multifunctional wireless sensor networks

Advanced wireless sensor networks that are automated, plug-and-play, and capable of monitoring multiple parameters through effective power management will enable a low-cost approach to accurately detect and diagnose failures and resulting inefficiencies in building equipment and systems. At the same time, they allow for optimal and localised whole-building control to improve building operations and reduce the energy used. In the execution, it aims at extending the operational lifetime of the sensors, reducing network infrastructure, and automating the configuration and calibration processes to reduce the cost by minimising the complexity of the sensor node architecture. Further details can refer to section 8.1.

### (ii) Advanced monitoring and data analytics

To provide essential data to help maximize and verify energy savings, advanced pervasive monitoring (e.g., sub-metering) and supporting analytics are aimed at allowing all relevant equipment and operations are being monitored at low cost and with sufficient accuracy and identification. They produce critical information on the state and usage patterns of specific equipment to enable monitoring-based commissioning, model calibration and training data collection for more sophisticated control strategies. In the advanced monitoring and analytics aspect, it is required to enhance the hardware accuracy, improve load disaggregation algorithms and other analytic techniques (e.g., Arc Fault Detection Device (AFDD)), and reduce the monitoring systems cost by material development in every load level. These facilitate the correction of anomalous behaviour to reduce whole-building energy use. Further details can refer to section 8.2.

### (iii) Adaptive and autonomous control

In developing integrated building control schemes for systems optimisation, the



predictive and adaptive capabilities of the control system are needed. The building control system shall be able to correct faults and respond to external conditions (e.g., weather forecasts, grid events) and aged building equipment conditions. The predictive and adaptive capabilities of the building control system allow the building equipment to operate as designed under the most energy-efficient status. An autonomous control system shall be embedded with a dynamic model that simulates stochastic variables with machine learning algorithms. The control system shall be trained to recognising complex patterns. Further details can refer to section 8.3.

**(iv) Occupant-centric controls**

Occupant-centric control schemes are essential in moving towards a more localised paradigm of building conditioning. The central system provides base-level conditioning. Personal preferences are feedback to the control system via local devices for optimisation as per occupants' needs. Accurate forecasting of individual and group-level occupant presence from the building control system allows for a comfortable environment and cost-effective building operation. The timely response and adjustments of equipment controllers enable the building equipment to suit occupancy patterns and occupants' preferences.

**(v) Others**

Other emerging technologies that can be used in retro-commissioning include advanced lighting systems, such as LED lighting and daylight harvesting systems, and advanced HVAC systems, such as variable refrigerant flow (VRF) systems and geothermal heat pumps. These technologies can provide significant energy savings and other benefits but may require a higher upfront investment than traditional retro-commissioning measures.

## **8.1. Multifunctional Wireless Sensor Networks**

Developing cost-effective, multi-sensing wireless networks with plug-and-play functionalities can speed up the deployment of sensor networks in buildings. It enables more efficient and effective building control strategies that save energy and allow more sophisticated and coordinated interactions with the electric grid. Without the need for power cables and wiring, wireless sensor networks represent a promising approach for data collection and monitoring building operations. These networks also enable flexibility in sensor placement and monitoring from remote locations, as well as the ability for relocation and reconfiguration of the system with changes in building

layouts. Many individual sensing elements for such wireless networks are commercially available and cost-effective. The following technical capabilities for multifunctional wireless sensor networks with plug-and-play functionality:

**(i) Long-lasting power sources**

The greater power efficiency of sensors will enable long-lasting power sources and reduce maintenance costs. Thus, low energy consumed sensors and more efficient energy harvesting and storage components can help. Moreover, the sensors shall be improved with several considerations, such as increasing the density and improving the performance of the power supply selected; optimising the design of the sensor architecture and circuitry for signal conditioning to achieve lower power processors and systems; optimising the network topology; increasing sensor communication range; and optimising data processing for the designated end-use application and antenna design.

**(ii) Automated sensor node calibration**

The sensor node shall be calibrated for several reasons, such as the sensing unit itself after manufacturing, the competence with the sensors, and the change or drift in sensor characteristics over time due to age or damage. In advanced sensor nodes, plug-and-play design and no need for manual recalibration are available, which allows for further reducing installation and maintenance costs. Automated calibration across the entire lifetime of accurate sensor operation is necessary. Moreover, the lifetime reliability and accuracy of the sensing unit itself for indoor air quality and humidity shall be increased through material interface improvements.

**(iii) Automated recognition and configuration**

Sensors placed within the range of a wireless network should automatically provide their identity, state, power use, and sensing capabilities to the network without requiring a physical connection. Automated sensor recognition should enable the location of sensors via unique identities and be supported by secure communications between the sensing elements and the building control system. The positional accuracy and overall percentage of sensors correctly mapped are important areas of improvement for such approaches. Accurate sensor placement through automated point mapping will help ensure higher-quality measurements and optimal energy harvesting. Automatic point mapping will also enable a more straightforward configuration of critical sensor information in a building management system, streamlining sensor deployment in more significant

buildings with many sensor nodes.

## **8.2. Advanced Monitoring and Data Analytics**

By capturing data downstream of the leading utility meter, advancements in sub-metering, coupled with load disaggregation and analytic techniques, will enable improvements to the monitoring of the actual energy consumption of individual building systems and components (e.g., air handlers and chillers), including the provision of information on the state and usage patterns of specific equipment along with essential data to verify energy savings. This level of granularity and ability to disaggregate loads can also serve as a means to monitor equipment health and usage. Comparing and verifying energy consumption enables monitoring-based commissioning as a substitute for or supplementing data streams from the BAS. GPS mapping & remote sensing can identify high-priority improvement areas through a smart grid. Further development of the advanced monitoring and data analysis can be considered as follow.

### **(i) Advanced materials development**

Enhancements to the accuracy and resolution or granularity of energy performance measurements through next-generation sub-meters require continued refinement of the magnetic properties of the materials selected and the supporting connectivity hardware. This will include modular design options for reducing the cost of the overall system and overcoming the installation challenges associated with connectivity to the electrical distribution system, as well as self-powered options to reduce total installation and maintenance costs.

### **(ii) Enhanced analytics**

Advancements in machine learning approaches offer an opportunity to continue to exploring and refining techniques for nonintrusive load monitoring and load disaggregation, an alternative to intrusive installation procedures and a solution to overcome limited flexibility in retrofitting existing meter deployments. In particular, improvements to the quality of interval data, the impact on the accuracy of model calibration and fault detection, as well as the resulting energy savings, should be further evaluated and verified. Data transfer quality in automatic meter readings and other communication solutions can also be further optimised through new and emerging analytical approaches. Machine learning approaches can also facilitate automated point mapping when installing analytic platforms on top of existing building automation system infrastructure.

**(iii) Automated calibration, configuration, and connectivity**

The ability to reduce measurement drift over time caused by age and damage, and automate the sub-meter calibration process, can enable plug-and-play functionality and further reduce installation and maintenance costs, which are especially sensitive to safety issues in metering applications. Automating the configuration process enables integration with legacy building automation systems to enhance the monitoring-based commissioning process, as well as a variety of data acquisition and transfer systems depending on the building configuration and measurement needs.

### **8.3. Adaptive and Autonomous Controls**

Building Automation Systems (BAS) allow building operators to monitor and control building systems, such as HVAC, lighting, and security, from a central location. BAS can optimise building performance by adjusting system settings based on occupancy, weather, and other factors. BAS systems can also monitor energy usage and provide real-time feedback to building operators to help them identify areas for improvement.

The development of control of the building level will focus on how to implement the control systems correctly and respond proactively to timely information about building operations and predictions, such as weather patterns, grid events, and a manifestation of faults and failures in equipment. This control shall with limited human intervention and aimed to enhance the performance of building operations. Adaptive controls represent a promising approach to adjusting building operations based on dynamic and shifting conditions that impact energy usage.

Advanced control schemes (e.g. Model Prediction Control) have demonstrated the adaptive control ability in some cases for building applications (e.g., precooling and preheating in large commercial buildings). Advancements in other sectors (e.g., industrial process control, automotive) can also be leveraged while addressing buildings-specific challenges. Performance improvements that minimize both manual and computational efforts in building control systems' development, integration, coordination, and tuning are necessary to achieve affordable and reliable control schemes at scale with sufficient spatial and temporal resolution. The development of the following technical capabilities for adaptive and autonomous controls are recommended for widely deployed for optimising building operations:

**(i) Improved forecasting**

Improved forecasting with finer spatial resolution and over longer time horizons for stochastic variable inputs (e.g., weather) through physics-based and data-driven models or historical data can improve the accuracy and performance of autonomous control solutions. Predictive & proactive mechanisms can learn the existing operating environment and map it with the best route by A.I. technologies for tuning the building performance. They improve the responsiveness of energy services and the prediction with respect to user behaviour. Proactive monitoring and improvements to predictive maintenance algorithms through the integration of real-time data about actual equipment performance, along with more realistic modelling of equipment degradation and faults, can enable more accurate predictions of future faults that impact operations and need to be accounted for in the control strategy selected. More realistic modelling of control sequences, along with the utilisation of reduced order models when the details of the physics of the building or system are limited, should be used in predictive control design.

**(ii) Optimised controls**

Control strategies that can capture the dynamics of the building with sufficient accuracy are required. These strategies should allow model development, calibration, and run times that are scalable and within the necessary time horizon for making adjustments to settings or taking corrective actions to maintain operations. Pattern recognition and machine-learning approaches, along with reduced order models, can be employed. Multi-objective optimisation and prioritisation are also necessary, along with optimisation across local and top-level controllers in hierarchical architectures. The development of hybrid Model Prediction Control (MPC) approaches, where reduced-order MPC models are automatically generated from more detailed BEM models, along with reinforcement learning techniques, can balance the trade-off of the approaches and develop flexible and reliable solutions that can tune to changing conditions with minimal customisation.

**(iii) Automated integration, coordination, and commissioning**

Equipment, devices and other systems components must be capable of automatically sharing their identity, status, and availability with advanced building controls. Machine learning enables societies to scrutinize the behaviour of Artificial intelligence (AI) systems and to allow the system to account for its operational procedures. Advances in AI are bolstered by the availability of massive amounts of data through the Internet and by the progress in sensory

technology together with machine learning. Since self-improvement through evolution is a basic tenet of machine learning systems, the pace of progress in many AI research areas has been considerable. Machine learning allows non-linear relationships to be determined, such as the relation between the energy demand and different relevant factors, through mapping functions from a training dataset (supervised learning), or any form of other datasets (unsupervised learning), even a sequence of decisions in an uncertain or a complex system. Machine learning approaches to facilitate the automation of the point mapping process and standardization of control sequences and verification tests in an open, digital format can streamline the installation and implementation process for control systems in the building design or retrofit phases. More rigorous evaluation of control algorithms and establishment of expected performance will be possible using recently developed building emulators.

#### **8.4. Summary for the adoption of innovative technologies in RCx**

Combing different intelligent building technologies can help the effectiveness of RCx in optimising energy consumption with satisfying occupants' needs. The ubiquitous monitoring of building and equipment conditions through low-cost wireless sensor networks and sub-metering solutions can enhance the evaluation of optimal parameters and resolution of data inputs to the building automation system and energy modelling. These data are used for developing, training, calibrating machine learning and forecasting. For example, site-specific weather forecasts for individual buildings can help adjust set points and calculating loads because weather-driven loads are the largest loads in buildings. Moreover, occupancy plays a vital role in tuning operating conditions to account for comfort and movement. With improved data collection, the verification and validation of control performance and projected energy savings can also benefit the outcomes of RCx processes.

## **9. Recommendations for boosting RCx implementation in the APEC region**

One of the key drivers behind the development of RCx in the APEC region is the recognition of the significant energy consumption and greenhouse gas emissions associated with buildings. According to the International Energy Agency (IEA),

buildings account for approximately 40% of global energy consumption and 33% of greenhouse gas emissions. Therefore, improving the energy efficiency of buildings is seen as a critical strategy for reducing greenhouse gas emissions and achieving sustainable development goals. In this connection, increasing RCx implementation for improving the energy efficiency of buildings shall be carried out. In this section, the recommendations for boosting RCx implementation in the APEC region are summarized in two aspects, (i) Critical factors for formulating the strategies for mainstreaming RCx and (ii) Common energy saving opportunities in RCx.

### **9.1. Critical factors for formulating the strategies for mainstreaming RCx**

The key factors which are critical in formulating the strategies for mainstreaming RCx in the APEC region are (i) The perceived value of RCx; (ii) The status of the industry; (iii) The necessary drivers; and (iv) The availability of open resources.

#### **(i) Perceived value of RCx**

The decision-making usually depends on the perceived value and is sometimes very subjective. Therefore, communication for exchanging and updating the values in the industry is important. Some stakeholders treat RCx as a means to save energy and money but cannot observe the need for digitalisation in this era. Therefore, there is a need to build up the competence of these stakeholders.

#### **(ii) Status of the industry**

The status of hardware, software and human resources in the industry for implementing RCx shall be reviewed. From the human resources perspective, one should start with priorities such as training, standards and guidelines, and the level of technologies adopted in existing buildings.

#### **(iii) Necessary drivers**

Drivers are essential for stepping up from conventional operation and maintenance practices to achieve updated energy reduction goals or adopt innovative technologies. The drivers can be the government's commitment to carbon neutrality and the associated codes and regulations, the certifications and awards for energy-efficient buildings, requirements for disclosures, etc.

#### **(iv) The availability of open resources**

It is helpful to establish an APEC RCx resources Hub to be served as a platform

for collaborations among APEC member economies to accelerate the mainstreaming of RCx. It can be a website where we can store and share documents such as technical guidelines, best practices, showcases, etc. We can include non-technical papers such as the strategies for promoting RCx in APEC member economies. We can also enable the website to take up a more active role. Pilot projects across the border using the different buildings in APEC region as living laboratories may be exhibited on the website for other economies to refer to. The third function can be sharing training or workshop information available in the APEC region. The hub can facilitate regional collaboration for energy efficiency and conservation.

## 9.2. Common energy saving opportunities in RCx

In the technical aspect, the common energy-saving opportunities of different building services systems are summarized below for capacity-building.

### (i) General problem for all systems

Common Issues Encountered in RCx	Energy Saving Opportunity (ESO)
Inaccuracy of sensors and/or insufficient sensors	<ul style="list-style-type: none"> <li>• Check the accuracy of the sensors and take calibration following the manufacturer’s recommendations;</li> <li>• Check if the sensing range of a sensor is compatible with the operating condition;</li> <li>• Check if the position of an installed sensor is appropriate or in accordance with the manufacturer’s instruction;</li> <li>• Conduct periodic checking on any out-of-range values.</li> </ul>

### (ii) Central air conditioning (Water-side)

Common Issues Encountered in RCx	Energy Saving Opportunity (ESO)
Temperature difference ( $\Delta T$ ) between main supply and return chilled water temperature is too low	<ul style="list-style-type: none"> <li>• Check and clean coils;</li> <li>• Check thermostat settings;</li> <li>• Verify that all coils have interlocking controls that ensure the control valves are closed;</li> <li>• Check if the modulating valve operation is</li> </ul>



	defective and/or the control/setting of AHU/PAU is improper.
Failure of chilled water zone control	<ul style="list-style-type: none"> <li>Inspect zone valve condition and repair/replace defective zone valve/controller</li> </ul>
Condensation on the surface of chilled water pipeworks and/or accessories	<ul style="list-style-type: none"> <li>Inspect the insulation and repair defective insulation</li> </ul>
Operating chiller capacity is greater than the required cooling load during the cool climate	<ul style="list-style-type: none"> <li>Adopt chilled water temperature reset to save chiller energy while cooling loads can still be catered</li> </ul>
Blockage of condenser tube	<ul style="list-style-type: none"> <li>Periodic maintenance of the condenser tube through monitoring of the pressure drop and the differential temperature</li> <li>Consider adopting an automatic cleaning system for the condenser tube to reduce the frequency and periodic maintenance to ensure the chiller efficiency and its expected life</li> </ul>

**(iii) Central air conditioning (Air-side)**

<b>Common Issues Encountered in RCx</b>	<b>Energy Saving Opportunity (ESO)</b>
AHU Fan with constant speed design only or Variable air volume control by fan inlet guide vanes or modulating damper	<ul style="list-style-type: none"> <li>Replace defective or loosened belt</li> </ul>
Indoor air temperature is too low	<ul style="list-style-type: none"> <li>Review/adjust the setpoint of the room thermostat to match operational needs;</li> <li>Check if sensors are correctly located.</li> </ul>
Indoor air distribution (Unbalancing in VAV air supply system)	<ul style="list-style-type: none"> <li>Check if variable-air-volume boxes are working properly</li> <li>Perform air balancing and adjust air dampers</li> <li>Replace defective damper or activator</li> </ul>
Air leakage from the air duct	<ul style="list-style-type: none"> <li>Inspect and repair the air ductwork</li> </ul>
Unsatisfactory cleanliness of air filter and/or cooling coil	<ul style="list-style-type: none"> <li>Replace/clean the air filter and/or cooling coil</li> </ul>

Incomplete or missing ductwork and pipework insulation	<ul style="list-style-type: none"> <li>Add ductwork and pipework insulation to reduce the amount of energy lost in transmitting heated or cooled fluids</li> </ul>
Review equipment operating schedules	<ul style="list-style-type: none"> <li>Check, update and review all equipment operation schedules making sure that they are on only when they are necessary</li> </ul>

**(iv) Lighting System**

<b>Common Issues Encountered in RCx</b>	<b>Energy Saving Opportunity (ESO)</b>
Over-illuminated in some areas	<ul style="list-style-type: none"> <li>Over-lit or underlit areas should be corrected</li> <li>Consider de-lamping some lighting at over-lit areas</li> </ul>
Lighting is “ON” during no occupancy period / non-peak hour period	<ul style="list-style-type: none"> <li>Add timer control or occupancy sensor control to match the operation schedule</li> <li>Replace the malfunction timer and/or occupancy sensor</li> </ul>
Insufficient calibration of the Lighting control system	<p>Time-based</p> <ul style="list-style-type: none"> <li>Correct operating schedule - lights are operating only when the building is occupied</li> </ul> <p>Occupancy based</p> <ul style="list-style-type: none"> <li>Adjust time-delay settings to suit the requirements of each space</li> <li>Check the sensor’s position</li> </ul> <p>Lighting level based</p> <ul style="list-style-type: none"> <li>Photocell controls should be checked to ensure desired daylighting dimming or daylight switching responses</li> <li>Setpoints should be adjusted so that the desired light levels are maintained</li> </ul>

**(v) Electrical System**

<b>Common Issues Encountered in RCx</b>	<b>Energy Saving Opportunity (ESO)</b>
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Insufficient review of power quality of the electrical distribution network	<ul style="list-style-type: none"> <li>• Check the operation of the capacitor bank and/or harmonic filter to enhance overall power quality and/or match operation needs/efficiency requirement</li> </ul>
Insufficient review of the total power factor for a circuit which is lower than the design value	<ul style="list-style-type: none"> <li>• Install power factor correction device if economically viable</li> </ul>
Total harmonic distortion of current for a circuit exceeds the limited design percentage	<ul style="list-style-type: none"> <li>• Install harmonic filter at the source of distortion to limit THD</li> </ul>
Insufficient power monitoring device	<ul style="list-style-type: none"> <li>• Install sufficient metering facilities to monitor the power consumption and energy performance of outgoing circuits</li> </ul>
Insufficient review of Tariff	<ul style="list-style-type: none"> <li>• Minimize maximum demand in peak hour</li> <li>• If possible, equipment should run during the less expensive off-peak hours</li> <li>• Consider applying pre-cooling strategies</li> </ul>

**(vi) Lift & Escalator**

<b>Common Issues Encountered in RCx</b>	<b>Energy Saving Opportunity (ESO)</b>
Insufficient administrative approach to optimise the operating quantity of Lift/Escalator with operation needs	<ul style="list-style-type: none"> <li>• Assign only one or two lifts available to casual end-users after regular working hours and on holidays</li> <li>• Encourage the end-users to walk up or down one or two-storey rather than taking a lift.</li> </ul>
Insufficient monitoring of power quality on the lift and escalator	<ul style="list-style-type: none"> <li>• Provide an electric filter to improve both the power factor and total harmonic distortion, irrespective of DCTL, VV or VVVF typed.</li> </ul>
Little energy saving measures in lift car and machine room	<ul style="list-style-type: none"> <li>• Switch on the lighting in the lift machine room only when it is occupied</li> <li>• Switch off all lighting and ventilation fan inside the lift car automatically when a lift is parked</li> </ul>

	<ul style="list-style-type: none"><li>• Switch off all ventilation fans and air-handling units in the lift machine room when all lifts have been parked for a significant period (e.g. at night)</li></ul>
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## 10. Conclusion

Retro-commissioning can be a cost-effective way to improve the performance of existing buildings, as it usually involves incremental improvements over time rather than implementing expensive upgrades all at once. Retro-commissioning can provide many benefits, including improved energy efficiency, indoor air quality, occupant comfort and equipment life. In addition, recommissioning can ensure that a building complies with current building codes and standards and can improve the building's resilience to power outages and other disruptions. The project aims to build RCx's capacity in low-carbon building operations and energy technology deployment through sharing experiences and knowledge-based best practices.

Retro-commissioning usually starts with a benchmarking process that involves collecting data on the building's energy use, indoor air quality and other performance indicators. This data is then used to determine where the building could be more efficient. Once the benchmarking process is complete, experts will thoroughly evaluate the building's systems, including HVAC, lighting and controls. They will look for opportunities to optimise performance, for example, by identifying equipment operating inefficiently, fixing leaks or other problems, or upgrading to more energy-efficient equipment. Once the assessment is complete, the experts will develop a plan to implement the recommended improvements. This may involve changes to the building's systems, such as adjusting heating and cooling settings, upgrading equipment, or installing new controls. Once the improvements have been implemented, the experts will monitor the performance of the building to ensure that the changes are delivering the desired results. Then, a training session will be provided for building operators and users to help them maintain the new performance levels of their buildings.

The development of RCx in the APEC region is a positive sign of the region's commitment to improving energy efficiency and reducing greenhouse gas emissions. These programs provide financial incentives, technical assistance, and training to help building owners and operators implement energy-saving measures and improve the performance of their buildings. As more buildings in the region undergo RCx, the benefits of improved energy efficiency, reduced costs, and enhanced occupant comfort will become more apparent, and the adoption of RCx practices will likely continue to grow.

The implementation of RCx programs in several APEC member economies reported the importance of improving building energy efficiency and reducing greenhouse gas emissions in the region. Further promoting RCx in the APEC region requires a multifaceted approach that involves engaging with different stakeholders, including governments, building owners and operators, and many strategies. The framework of RCx implementation is summarised into four groups in this report, i.e. (i) Target and policy; (ii) Collaboration; (iii) Technical support; and (iv) Financial support. It is observed that the transformation of industry culture from experience-based to knowledge-based and the capacity-building of innovative technologies for enabling RCx works are essential for stimulating RCx implementation. APEC member economies can raise awareness of RCx among building owners, operators, and the general public. This can include educational campaigns, outreach efforts, and media coverage to highlight the benefits of RCx and promote energy efficiency in buildings. APEC member economies can engage with building industry associations to promote RCx and energy efficiency in buildings. We need to enhance the competencies of the practitioners through systemic training. The qualification of these practitioners shall be recognised through registration or certification schemes. These associations can raise awareness among their members and provide training and resources to promote RCx services. It is important to raise the image and competence of practitioners or professionals in society, with the contribution from the building industry associations.

Apart from the desktop study, a 1.5-day workshop cum training was organised. The benefits of RCx in addition to saving energy and money in the short term were discussed at the workshop. Besides the capacity-building and direct dialogue opportunities provided by the workshop cum training, another outcome from the workshop cum training is the suggestion to organise an RCx Resources Hub. The RCx Resources Hub will help facilitate collaboration & sharing of RCx adoption among the APEC member economies. The hub will be the centre for sharing strategies, showcasing successful projects from different economies, and supporting the pursuit of technology and knowledge transfer through co-organising competitions, technical sharing events and training etc.

This report demonstrates that the objectives of the project are achieved, including the report on RCx implementation frameworks and guidelines and the provision of a workshop cum training course of capacity-building, to promote the development of energy efficiency and low-carbon measures across the APEC region.

## 11. References

- (1) “California Commissioning Guide: Existing Buildings”, Portland Energy Conservation Inc (2006),  
[https://cxwiki.dk/files/stream/public/CA\\_Commissioning\\_Guide\\_Existing.pdf](https://cxwiki.dk/files/stream/public/CA_Commissioning_Guide_Existing.pdf)
- (2) “What is a Building Tune-Up?”, Office of Sustainability & Environment (2016) ,  
<http://www.seattle.gov/environment/climate-change/buildings-and-energy/building-tune-ups/about-building-tune-ups>
- (3) “Handbook of Green Building Design and Construction (Second Edition), Chapter Eleven - Green Project Commissioning”, LEED AP (2017),  
<https://www.sciencedirect.com/science/article/pii/B9780128104330000113>
- (4) “New Construction Commissioning”, Bolder Energy Engineers,  
<https://www.bolderee.com/new-construction-commissioning.html>
- (5) “TS 5342:2021, Building Commissioning”, Standards Australia (2021),  
<https://www.standards.org.au/news/an-australian-first-building-commissioning-technical-specification>
- (6) (Not used)
- (7) “Commissioning, Re-Commissioning & Retro-Commissioning: What’s The Difference?”, Kirsten McCann, McKenney's (2017),  
<https://www.mckenneys.com/2017/09/commissioning-re-commissioning-retro-commissioning-whats-the-difference/>
- (8) “Technical Guidelines on Retro-commissioning”, Electrical and Mechanical Services Department, The Government of the Hong Kong Special Administrative Region (2018), [https://www.rcxrc.emsd.gov.hk/uploads/en/technicalguide/EMSD-TG-RCx--Main-Content\\_EN\\_Rev1\\_.pdf](https://www.rcxrc.emsd.gov.hk/uploads/en/technicalguide/EMSD-TG-RCx--Main-Content_EN_Rev1_.pdf)
- (9) “公共建筑机电系统调适技术导则”，中国建筑科学研究院有限公司 (2020),  
<http://www.cecs.org.cn/a/infos/xiehuibiaozhun/2021/0527/11973.html>
- (10) “Retrocommissioning Buildings for Energy Efficiency Learner Guide”, the Australian Institute of Refrigeration, Air Conditioning and Heating (2011),  
<http://www.environment.nsw.gov.au/resources/eetp/retrolearngd1.docx>
- (11) “Recommissioning Terminology”, Government of Canada (2016),  
<https://www.nrcan.gc.ca/energy/efficiency/data-research-and-insights-energy-efficiency/buildings-innovation/building-optimization/recommissioning/rcx-guide/recommissioning-terminology/3797>
- (12) “Retro-Commissioning (RCx) and Leveraging Your Building Automation System for Energy Efficiency”, Dan Doyle, P.E., LEED AP, Grumman/Butkus Associates

- Energy Efficiency Consultants and Sustainable Design Engineers (2011),  
[https://www.e2singapore.gov.sg/DATA/0/docs/05%20Dan%20Doyle\\_neeconf.pdf](https://www.e2singapore.gov.sg/DATA/0/docs/05%20Dan%20Doyle_neeconf.pdf)
- (13) “建築物進駐後運轉與線上調適之節能效果應用分析”, Architecture and Building Research Institute, Ministry of Chinese Taipei,  
[https://www.abri.gov.tw/News\\_Content\\_Table.aspx?n=807&s=38844](https://www.abri.gov.tw/News_Content_Table.aspx?n=807&s=38844)
- (14) “我国建筑调适发展现状与前景”, 第二届全国建筑调适与运维大会系列专家报告, 逢秀锋(2021), <https://www.ccbco.cn/newsinfo/505914.html>
- (15) “O&M Best Practices Guide, Release 3.0 - Chapter 7 Commissioning Existing Buildings”, The U.S. Department of Energy’s Federal Energy Management Program (2010), [https://www1.eere.energy.gov/femp/pdfs/om\\_7.pdf](https://www1.eere.energy.gov/femp/pdfs/om_7.pdf)
- (16) “Existing Building Commissioning Best Practices”, The Building Commissioning Association (2020), <https://www.bcx.org/wp-content/uploads/2019/09/EBCx-BEST-PRACTICES-Final.pdf>
- (17) “コミ ッ シ ョ ニ ン グ と は”, Building Services Commissioning Association , Japan (2004), <http://www.bsca.or.jp/outline/commissioning02.html>
- (18) National Construction Code (2020), <https://ncc.abcb.gov.au/>
- (19) Handbook: Upgrading existing buildings,  
<https://ncc.abcb.gov.au/sites/default/files/resources/2022/Handbook-upgrading-existing-buildings.pdf>
- (20) Energy efficiency in commercial buildings,  
[https://www.nabers.gov.au/sites/default/files/energy\\_efficiency\\_in\\_commercial\\_buildings\\_full\\_length\\_guide.pdf](https://www.nabers.gov.au/sites/default/files/energy_efficiency_in_commercial_buildings_full_length_guide.pdf)
- (21) “HVAC factsheet - Commissioning and building tuning”, 2013, Department of the Environment and Energy, the Government of Australia,  
<https://www.energy.gov.au/sites/default/files/hvac-factsheet-commissioning-building-tuning.pdf>
- (22) Greening Your Building Toolkit,  
<https://www.melbourne.vic.gov.au/SiteCollectionDocuments/greening-your-building-toolkit.pdf>
- (23) AIRAH Training: Building Tuning,  
[https://www.airah.org.au/Education/AIRAH\\_Courses/Technical\\_courses/Sustainability/Building\\_Tuning.aspx](https://www.airah.org.au/Education/AIRAH_Courses/Technical_courses/Sustainability/Building_Tuning.aspx)
- (24) Sustainable Melbourne Fund,  
<https://www.melbourne.vic.gov.au/business/sustainable-business/Pages/sustainable-melbourne-fund.aspx>
- (25) Building Optimization, the Government of Canada, <https://natural-resources.canada.ca/energy-efficiency/data-research-insights-energy-ef/buildings-innovation/building-optimization/3695>



- (26) Tuning Up: A Framework for Existing Building Commissioning, <https://natural-resources.canada.ca/sites/nrcan/files/energy/pdf/tuning-up-a-framework-for-existing-building-commissioning.pdf>
- (27) Recommissioning Guide For Building Owners and Managers, Natural Resources Canada, [https://natural-resources.canada.ca/sites/nrcan/files/canmetenergy/pdf/fichier.php/codectec/En/2008-167/NRCan\\_RCx\\_Guide.pdf](https://natural-resources.canada.ca/sites/nrcan/files/canmetenergy/pdf/fichier.php/codectec/En/2008-167/NRCan_RCx_Guide.pdf)
- (28) Advanced Building Recommissioning Course, <https://natural-resources.canada.ca/energy/efficiency/data-research-and-insights-energy-efficiency/buildings-innovation/building-optimization/recommissioning/advanced-building-recommissioning-course/3811>, <https://cietcanada.com/news/commissioning-vs-recommissioning/>
- (29) Community building recommissioning grant, Federation of Canadian Municipalities, <https://greenmunicipalfund.ca/funding/community-building-recommissioning-grant>
- (30) Recommissioning (RCx) Pre-Screening Tool, CanmetENERGY, <https://natural-resources.canada.ca/sites/nrcan/files/canmetenergy/files/RCx%20%20Screening%20Form%20EN.pdf>
- (31) Benchmarking Tool, CanmetENERGY, <https://natural-resources.canada.ca/energy/efficiency/data-research-and-insights-energy-efficiency/buildings-innovation/building-optimization/recommissioning/benchmarking-tool/3807>
- (32) Recommissioning Data Collection Form., CanmetENERGY, [https://natural-resources.canada.ca/sites/nrcan/files/files/excel/NRCan\\_RCx\\_Data\\_Form.xls](https://natural-resources.canada.ca/sites/nrcan/files/files/excel/NRCan_RCx_Data_Form.xls)
- (33) Energy Saving Plan for Hong Kong's Built Environment 2015~2025+, Environment Bureau of Hong Kong, China, <https://www.enb.gov.hk/sites/default/files/pdf/EnergySavingPlanEn.pdf>
- (34) Climate Action Plan 2050, Environment Bureau of Hong Kong, China, [https://www.climate-ready.gov.hk/files/pdf/CAP2050\\_booklet\\_en.pdf](https://www.climate-ready.gov.hk/files/pdf/CAP2050_booklet_en.pdf)
- (35) Technical Guideline on Retro-commissioning (2017 and 2018), Electrical and Mechanical Services Department of Hong Kong, China, [https://www.rcxrc.emsd.gov.hk/en/technical\\_guideline.php](https://www.rcxrc.emsd.gov.hk/en/technical_guideline.php)
- (36) Strengthening the Technical Capability and Regional Collaboration in Implementing Retro-commissioning (RCx) in Buildings, Building Services Operation and Maintenance Executives Society (BSOMES), <https://www.bsomes.org.hk/index.php/resources-center/resource-center-publications/167-strengthening-the-technical-capability-and-regional-collaboration-in-implementing-retro-commissioning-rcx-in-buildings>

- (37) RCx Training and Registration Scheme, Hong Kong Green Building Council,  
<http://retro.hkgbc.org.hk/textdisplay.php?serial=4>
- (38) Green Schools 2.0 for Retro-commissioning, Hong Kong Green Building Council,  
<http://greenschools2.hkgbc.org.hk/training.php?action=1&page=2>
- (39) Global Warming Countermeasure Plan (translated from “地球温暖化対策計画”),  
Ministry of the Environment of Japan,  
<https://www.env.go.jp/content/900447150.pdf>
- (40) News of launching the Cx Manual, Building Services Commissioning Association,  
<http://www.bsca.or.jp/members/news/?act=detl&id=56>, <http://www.bsca.or.jp/news-letter/news/870/>
- (41) Commissioning Professional Engineer (CxPE), Building Services Commissioning  
Association, <http://www.bsca.or.jp/english/qualification/cxpe.html>
- (42) Commissioning Technical Engineer (CxTE), Building Services Commissioning  
Association, <http://www.bsca.or.jp/english/qualification/cxte.html>
- (43) Commissioning Tool Library, Building Services Commissioning Association,  
<http://www.bsca.or.jp/tools-library/>
- (44) US Code 42 U.S.C. § 8253(f)(3)(A) - Energy and Water Evaluations and  
Commissioning,  
[https://www7.eere.energy.gov/femp/requirements/laws\\_and\\_requirements/energy\\_a  
nd\\_water\\_evaluations\\_and\\_commissioning\\_0](https://www7.eere.energy.gov/femp/requirements/laws_and_requirements/energy_and_water_evaluations_and_commissioning_0)
- (45) Local Law 87 “Energy Audits and Retro-Commissioning (Retro-Cx)”, New York  
City, [https://www.nyc.gov/site/buildings/codes/energy-audits-retro-  
commissioning.page](https://www.nyc.gov/site/buildings/codes/energy-audits-retro-commissioning.page)
- (46) Commercial Energy Efficiency Ordinance of Atlanta,  
<https://atlantabuildingbenchmarking.com/about/>
- (47) Seattle’s Building Tune-Ups Ordinance,  
[https://www.seattle.gov/environment/climate-change/buildings-and-  
energy/building-tune-ups/about-building-tune-ups](https://www.seattle.gov/environment/climate-change/buildings-and-energy/building-tune-ups/about-building-tune-ups)
- (48) Seattle's Climate Action Plan (2013),  
[https://www.seattle.gov/documents/Departments/OSE/2013\\_CAP\\_20130612.pdf](https://www.seattle.gov/documents/Departments/OSE/2013_CAP_20130612.pdf)
- (49) Energy Audits and Retro-Commissioning: State and Local Policy Design Guide and  
Sample Policy Language, Department of Energy,  
[https://www.energy.gov/sites/default/files/2021-  
07/commercialbuildings\\_audits\\_rcx\\_policy\\_guide.pdf](https://www.energy.gov/sites/default/files/2021-07/commercialbuildings_audits_rcx_policy_guide.pdf)
- (50) Commissioning for Federal Facilities, Department of Energy,  
[https://www.energy.gov/sites/prod/files/2014/07/f17/commissioning\\_fed\\_facilities.p  
df](https://www.energy.gov/sites/prod/files/2014/07/f17/commissioning_fed_facilities.pdf)

- (51) Operations & Maintenance Best Practices (Release 3.0), Department of Energy, [https://www.energy.gov/sites/prod/files/2020/04/f74/omguide\\_complete\\_w-eo-disclaimer.pdf](https://www.energy.gov/sites/prod/files/2020/04/f74/omguide_complete_w-eo-disclaimer.pdf)
- (52) ACG Commissioning Guideline, ABC Commissioning Group (ACG), <http://www.commissioning.org/certificationrequirements/>
- (53) Building Commissioning Professional (BCxP) Study Guide, American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), [https://www.techstreet.com/ashrae/standards/certification-study-guide-building-commissioning-professional-bcxp?product\\_id=2504669](https://www.techstreet.com/ashrae/standards/certification-study-guide-building-commissioning-professional-bcxp?product_id=2504669)
- (54) Ongoing Commissioning Best Practices, Building Commissioning Association (BCxA), <https://www.bcx.org/>
- (55) RCx specification, National Environmental Balancing Bureau (NEBB), <https://nebb.org/disciplines/retro-commissioning-of-existing-buildings/>
- (56) Better Buildings Workforce Guidelines, Department of Energy, <https://www.energy.gov/eere/buildings/downloads/better-buildings-workforce-guidelines>
- (57) CxA program, ACG, <http://www.commissioning.org/certificationrequirements/>
- (58) Building Commissioning Professional (BCxP) certification program, ASHRAE. <https://www.ashrae.org/professional-development/ashrae-certification/certification-types/bcxp-building-commissioning-professional-certification>
- (59) BCxP Study Guide, ASHRAE, [https://www.techstreet.com/ashrae/standards/certification-study-guide-building-commissioning-professional-bcxp?product\\_id=2504669](https://www.techstreet.com/ashrae/standards/certification-study-guide-building-commissioning-professional-bcxp?product_id=2504669)
- (60) Smart Energy Analytics Campaign, Department of Energy, <https://betterbuildingsolutioncenter.energy.gov/alliance/technology-campaigns/smart-energy-analytics-campaign>
- (61) Smart Energy Analytics Campaign result, <https://smartenergyanalytics.org/>
- (62) Technical Notes 2024 (NIST.TN.2024) “Commissioning ASHRAE high-performance sequences of operation for multiple-zone variable air volume air handling units”, National Institute of Standards and Technology (NIST) of the Department of Commerce in United States, <https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2024.pdf>
- (63) Technical Notes 2027 (NIST.TN.2027) is titled “Retro-commissioning a performing arts centre using HVAC-Cx”, NIST, <https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2027.pdf>
- (64) Retro-Commissioning (RCx) Pilot Program, <https://nj.gov/bpu/newsroom/news/pdf/20091216.pdf>

- (65) Existing Building Commissioning (EBCx) program, Seattle City Light, <https://www.seattle.gov/documents/Departments/CityLight/EBCxReqs.pdf>
- (66) Reasons for implementing RCx, Natural Resources of Canada, <https://natural-resources.canada.ca/energy-efficiency/buildings/existing-buildings/recommissioning/20705>
- (67) Building Energy Efficiency Certificate, Australian Government, <https://www.cbd.gov.au/program/beec/what-beec-building-energy-efficiency-certificate>
- (68) Environmental Upgrade Finance, Sustainability Victoria, Victoria State Government, Australia, <https://www.sustainability.vic.gov.au/energy-efficiency-and-reducing-emissions/in-a-business/finance-energy-upgrades-in-your-business/environmental-upgrade-finance-for-business>
- (69) Sustainable Australia Fund, <https://sustainableaustraliafund.com.au/who-we-are/>
- (70) Efficient Heating, Ventilation and Air conditioning (HVAC) Operation during a Pandemic: Self-evaluation Tool and Guide, Natural Resources Canada, <https://natural-resources.canada.ca/energy-efficiency/buildings/existing-buildings/recommissioning/efficient-heating-ventilation-and-air-conditioning-hvac-operation-during-pandemic-sel/23577>
- (71) Re-tuning in Federal Buildings, Office of Federal Energy Management Program, Department of Energy, United States, <https://www.energy.gov/femp/re-tuning-federal-buildings>
- (72) RCx Resource Centre, EMSD, Hong Kong, China, <https://www.rcxrc.emsd.gov.hk/en>
- (73) Design Application manual DA27, Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH), Australia (2011), <https://www.airah.org.au/ItemDetail?iProductCode=DA27&Category=DAMANUALS&WebsiteKey=31502b89-5f68-472f-b0e9-cee374551e18>
- (74) SA TS 5342:2021 Building Commissioning, Standards Australia (2021), <https://www.standards.org.au/news/an-australian-first-building-commissioning-technical-specification>
- (75) San Francisco's Existing Commercial Buildings Energy Performance Ordinance, <https://sfenvironment.org/existing-buildings-energy-performance-ordinance/>
- (76) Building Energy and Water Efficiency Strategy, City of Orlando, <https://www.orlando.gov/Initiatives/Building-Energy-Water-Efficiency-Strategy>
- (77) ASHRAE Guideline 0.2, <https://www.ashrae.org/about/news/2015/new-ashrae-guideline-focuses-on-optimum-facility-and-system-operation>

- (78) “Making the Leap: Data and Lessons Learned from Scaling Up Retrocommissioning Programs”, Portland Energy Conservation, Inc,  
[https://www.aceee.org/files/proceedings/2008/data/papers/4\\_169.pdf](https://www.aceee.org/files/proceedings/2008/data/papers/4_169.pdf)