Project Summary Report

EBC

Energy in Buildings and
Communities Programme

EBC Annex 47

Cost Effective Commissioning of Existing and Low Energy Buildings

Daniel Choinière

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Project Summary Report

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Published by AECOM Ltd, AECOM House, 63 - 77 Victoria Street, St Albans,
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International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster co-operation among the twenty-eight IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

Energy in Buildings and Communities

The IEA co-ordinates research and development in a number of areas related to energy. The mission of one of those areas, the EBC - Energy in Buildings and Communities Programme, is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)
The research and development strategies of the EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshop, held in April 2013. The R&D strategies represent a collective input of the Executive Committee members to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy conservation technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas of R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date the following projects have been initiated by the executive committee on Energy Conservation in Buildings and Community Systems (completed projects are identified in grey):

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Annex 2:	Ekistics and Advanced Community Energy Systems
Annex 3:	Energy Conservation in Residential Buildings
Annex 4:	Glasgow Commercial Building Monitoring
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities
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Working Group - Energy Efficiency in Educational Buildings
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings
Working Group - Annex 36 Extension: The Energy Concept Adviser

General Information

Project leader: **Daniel Choinière, Natural Resources Canada, Canada and Natascha Milesi-Ferretti, National Institute of Standards and Technology, USA**

Project duration: **2005 - 2010**

Further information: **www.iea-ebc.org**

Commissioning methods and tools are required to ensure that advanced components and systems for buildings reach their technical potential and operate energy-efficiently. Likewise, commissioning methods and tools should strive to improve the energy efficiency of conventional and advanced existing buildings beyond just the design intent. The goal of the project is to enable the effective commissioning of existing and future buildings in order to improve their operating performance. The aim is to advance the state-of-the-art of building commissioning by:

– Extending previously developed methods and tools to address advanced systems and low energy buildings, utilizing design data and the buildings' own systems in commissioning;

– Automating the commissioning process to the extent practicable;

– Developing methodologies and tools to improve operation of buildings in use, including identifying the best energy saving opportunities in heating, ventilation and air conditioning (HVAC) system renovations;

– Quantifying and improving the costs and benefits of commissioning, including the persistence of benefits and the role of automated tools in improving persistence and reducing costs without sacrificing other important commissioning considerations.

To accomplish these objectives the project has conducted research and development in the following three areas:

– **Initial Commissioning of Advanced and Low Energy Building Systems** - This area addressed what can be done for the design

Participating Countries:

Belgium
Canada
Czech Republic
Finland
France
Germany
Hong Kong/China
Hungary
Japan
the Netherlands
Norway
USA

Figure 1 Annex 47 reports

of future buildings to enable cost-effective commissioning. The focus was on the concept, design, construction, acceptance, and early operation phase of buildings.

- **Commissioning and Optimization of Existing Buildings** - This area addressed needs for existing buildings and systems to conduct cost-effective commissioning. The focus here was on existing buildings for which the commissioning process must be performed with incomplete or out-of-date documentation.

- **Commissioning Cost-Benefits and Persistence** - This area addressed how the cost-benefit situation can be represented. Key answers were provided by developing international consensus methods for evaluating commissioning cost-benefit and persistence. The methods were implemented in a cost-benefit and persistence database using field data.

In 2006, researchers from 22 organizations in ten countries began a joint effort to enable the cost-effective commissioning of existing and future buildings to improve the buildings' operating performance. The commissioning techniques developed through this project are intended to help transition the industry from the intuitive approach, currently employed in the operation of buildings, to more systematic operation focusing on achieving significant energy savings.

Key outputs of EBC Annex 47 'Cost Effective Commissioning of Existing and Low Energy Buildings' include:

- methods and tools for commissioning advanced systems and low energy buildings,

- methods and tools for field application, and

- information on the costs and benefits that can be used to promote the wider use of commissioning.

Project Outcomes

Project leader: Daniel Choinière, Natural Resources Canada, Canada and Natascha Milesi-Ferretti, National Institute of Standards and Technology, USA
Project duration: 2005 - 2010
Further information: www.iea-ebc.org

Introduction

Building commissioning (Cx) is a cost-effective way for building owners to ensure that buildings reach their operating potential. When a building is commissioned it goes through a systematic, quality assurance process. This process, which spans the design, construction, and operation of the building and its systems, is a valuable mechanism for quality building delivery. The process is aligned with industry best-practices, and involves commissioning agents, building owners, architects, engineers, and building operators. It includes:

- developing documents such as the owner's project requirements;
- planning for and carrying out verification checklists and functional tests;
- developing a complete systems manual and training requirements;
- performing seasonal / deferred testing.

Commissioning ensures that the building meets the owner's needs and operates efficiently, and lays the groundwork for training the operations and maintenance staff to maintain systems over the life of the building. The overarching benefits include reduced lifecycle costs, improved occupant comfort and productivity, and cost-effective maintenance. Table 1 presents a summary of the range of costs and benefits reported from 12 cost-benefit commissioning studies that were conducted outside of this project. The number of buildings evaluated in the studies ranged from 1 to 175 and are summarized in Table 1.

Commissioning Process and Market Penetration

Early investors in the commissioning process have attempted a number of different development paths including national research programs, industry guidelines, government

	New construction ($/ft^2) ($/m^2)	Existing buildings ($/ft^2) ($/m^2)
Cx / EBCx cost	$0.19 to $1.00 $2.05 to $10.76	$0.08 to $0.40 $0.86 to $4.31
Energy benefits	$0.05 to $0.64 $0.54 to $6.89	$0.11 to $0.26 $1.18 to $2.80
Non-energy benefits	$0.13 to $2.10 $1.40 to $22.60	$0.11 to $0.18 $1.18 to $1.94
Simple payback	4.8 y to 6.5 y	0.7 y to 3.2 y

Table 1 Summary of range of costs and benefits from 12 studies (from Report 3, Table 2.1) [i]

[i] Costs and benefits are presented as ranges to demonstrate the variances in the studies examined. Median or average values are not presented because underlying methodologies differ widely and such figures would not reflect actual costs and benefits experienced by building owners.

mandates, training programs, demonstration projects, international collaborations, and the creation of non-profit organizations to gather resources and disseminate information. One of the most promising of these is the establishment of commissioning demonstration projects with detailed information about the associated costs and benefits of the process. The need for quantitative and qualitative information (beyond anecdotal reports) is universal. Demonstration projects can provide a foothold for the industry and justify the large owner mandates, national mandates, and additional measures that are needed to scale up the adoption of commissioning as standard practice. The dissemination of information and education is also a critical component in establishing the commissioning process. Non-profit organizations have played a key role in fostering interest in commissioning research and commissioning projects and exchanging information, first on national levels, and increasingly at international levels.

Although the goals of reducing energy consumption and greenhouse gases are gaining political support, investment still lags behind. There is a disparity between those who must invest in the development of commissioning technologies and those who would benefit. Because adoption has been slow, public and private partnerships are needed to grow both the supply side and the demand side of the commissioning market. On the supply side, there is a need for greater standardization of products and services. There is a dramatic shortage of skilled providers and a lack of resources to enable the industry to improve the building delivery process. On the demand side, resources are needed to make the business case for the long-term benefits of their investment. Owners lack the resources, such as contracting documents, and market information that is needed to facilitate the procurement of commissioning services. Harmonization of commissioning services is needed to assure that the process adequately spans the building lifecycle and to ensure that the benefits obtained in individual projects can be scaled up to meet national needs. Continued support for the development of the commissioning market is needed for a global increase in building performance.

Report 1, 'Commissioning Overview' provides an introduction to the commissioning process. The project results also serve as a means to document information on commissioning practices in different countries and to disseminate relevant information to national practitioners.

Methods and Tools for Commissioning Advanced Systems and Low Energy Buildings

The project identified that a major barrier to market penetration stems from the lack of commissioning methods and tools to ensure that advanced components and systems reach their technical potential and operate energy-efficiently. Results of research to develop guidelines and tools to help overcome that barrier for both existing and future buildings are presented in Report 2, 'Commissioning Tools for Existing and Low Energy Buildings'. Report 2 provides general information on the use of tools to enhance the commissioning of low energy and existing buildings, summarizes guidelines for monitoring and the use of sensors, and presents a collection of international case studies.

Commissioning – and especially on-going commissioning – must cope with vast amounts of information and data. Information on the building's characteristics and heating, ventilating, and air-conditioning (HVAC) system, as well as measured data, e.g., of the energy consumption, state variables or control signals, must be managed. In more complex or low energy buildings with advanced technologies this task requires computer-aided processes or software tools because humans cannot manage the wealth of data or extract specific information. The tools and case studies discussed in Report 2 illustrate the potential for improved building performance through the use of software tools in the commissioning process. They provide features for operational fault detection and diagnosis (FDD) and / or for optimization that help to identify and realize potential savings. Most developed tools focus on the operation phase (existing buildings). Only a handful address the design phase (new constructions). This seems natural as commissioning has close ties to the operation phase and most of the built environment is already constructed. However, ideally, commissioning starts in the early design phase of construction. In this context, it should be noted that design and operation phases demand very different tool features.

Tools for the design phase (new construction)

The design phase is characterized by considerable choice in solutions for building construction and HVAC systems. The design team must find a way to meet the owner's project requirements (OPR). Typically this involves comparing various design alternatives that (ideally) are based on simulation. Consequently, a design phase Cx tool should support the assessment of different design alternatives.

More important is documentation of the OPR, basic design, target values (e.g., energy demand), and all decisions and knowledge gathered during the design phase. This information is essential to measurement and verification in the later operation phase. The current absence of complete and / or up-to-date building documentation is one of the biggest barriers to the introduction of commissioning in existing buildings. Cx tools should therefore support information management over the building's lifecycle.

Tools for the operation phase (existing buildings)

In the operation phase, most commissioning is made up of FDD and optimization. Unlike in the design phase, the commissioning provider must deal with a given system without a chance to replace major equipment (as long as no significant refurbishment is planned). In fact, many existing buildings were not commissioned during the design phase and many may not even have been commissioned during hand over. As a result, the commissioning provider must often cope with a situation in which there is a lack of information and little measured data exist. Consequently, the features and scope of the operation phase vary significantly, depending on the data and information needed to apply the tool.

Report 2 also gives an overview of tools developed in the project and also addresses data visualization - a feature identified as vital for revealing hidden information. Depending on the system to be evaluated, the questions to be answered and the time resolution of the measured data or analysis, different visualizations can be used separately or in combination. Principally, visualization techniques can be used to show:

– Change of variables over time

– Relations between two or more variables

– Statistical information / distribution of values

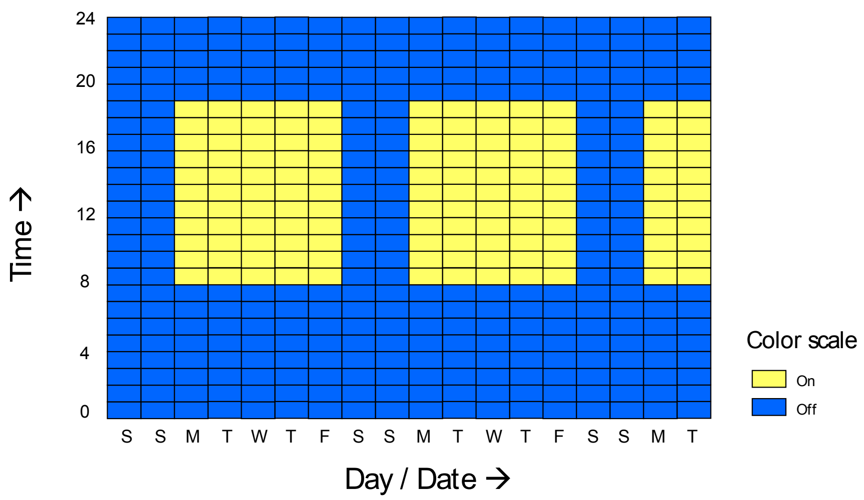


Figure 1 Ideal carpet plot example (e.g. a fan running Monday to Friday from 8:00 to 18:00)

– Spatial information / distribution

– Partitioning / percentage share of properties

– Comparison of scalars (elements of different size)

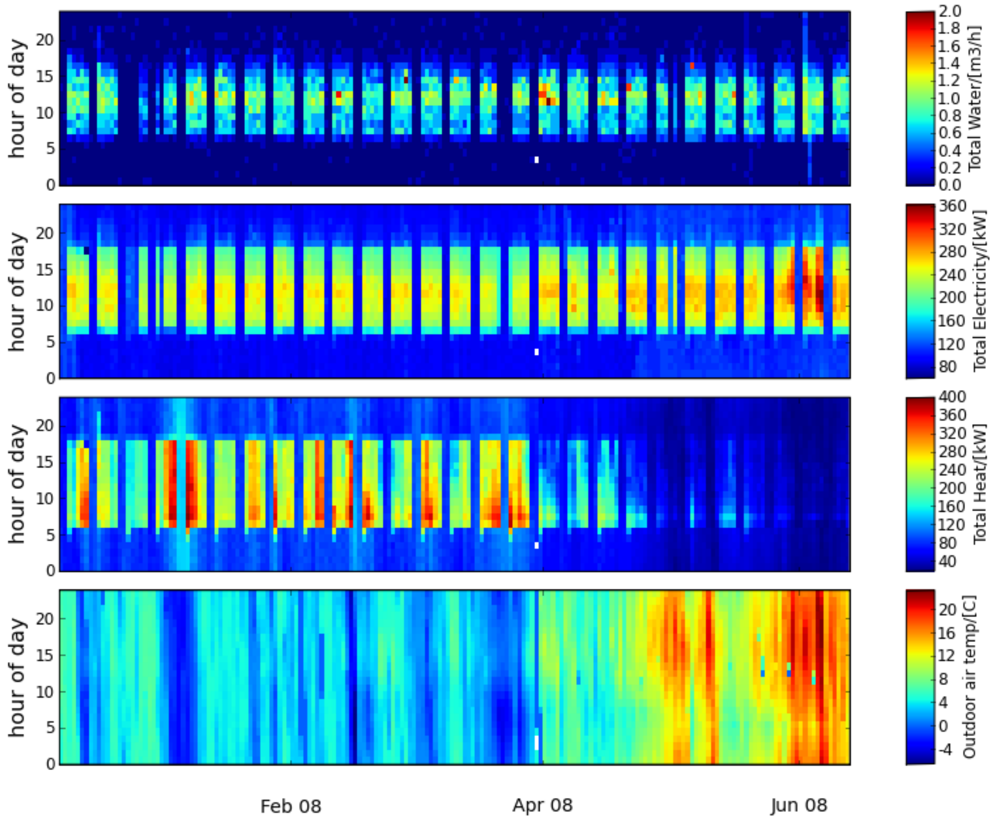
– Process / information flow.

An example of a visualization technique used for presenting a change of variables over time is a ‘carpet plot’ graph. Carpet plots are used to display (long) time series of a single variable in the form of a color map, which often reveal a pattern (like weekly operations) as shown in Figures 1 and 2. Figure 1 shows an ideal carpet plot example. The course of each day runs along the y-axis from the “bottom” (y=0:00) to the “top” (y=23:00) and days are plotted next to each other accordingly on the x-axis. Measurement values are portrayed in different colours. For days with a similar course of measurement values, the colour pattern is respectively similar. Figure 2 depicts an actual example. Naturally, the patterns are more blurred compared to the ideal example.

Tools to ensure persistence

The international status of on-going commissioning and Cx tool requirements can be summarized as follows: There is no common understanding of the term ‘on-going commissioning’ among the different countries. With the exception of the USA, on-going commissioning has yet to be established as a well-defined, third-party service. Nevertheless, every country offers services that form part of the on-going commissioning process and experts stress its importance for the persistence of energy efficient operation of buildings. All countries (including the USA) state that there

Figure 2 Carpet plot for real weather and consumption data



are few, if any, commercial and / or easy to use tools available that can be used for on-going commissioning. Moreover, all countries state that automation of the tools and thereby a reduction of labour cost associated with the process is crucial for a wider application. Cost-benefits of on-going commissioning tool application have yet to be documented.

The project team identified the following needs for further research and tool development to support on-going commissioning in new and existing buildings:

– Automation and a more robust application of tools (e.g., for FDD or functional testing) remains an important issue to reduce costs.

– Tools should be better integrated, i.e., not just provide one feature like FDD for an air-handling unit. This will make the application of tools increasingly relevant to building owners or operations staff. The number of tools required to cover all on-going commissioning-required functionalities should be reduced.

– Tools must be made easy to use and their interfaces improved.

Finally, tools should be better integrated in the whole commissioning process. To do so, the process itself must be better defined and standardized. An example is the need for monitoring guidelines.

Commissioning Cost-Benefit and Persistence

Research on commissioning cost-benefits and persistence addressed how the cost-benefit situation can be represented. Twelve studies were summarized, focusing on where the cost-benefit methodologies were known. The majority were research studies of multiple buildings, and the studies ranged from research reports, databases, and marketing literature. Key answers were provided by developing international consensus methods for evaluating commissioning cost-benefit and persistence. The methods were implemented in a cost-benefit and persistence database using field data. Financial and technical data was collected and analyzed from 10 new building commissioning projects and 44 existing building commissioning projects, from seven countries. Results are published in Report 3 'Commissioning Cost Benefit and Persistence of Savings'. The report also highlights national differences in the application of commissioning.

The data collected through this research project begins to characterize the various types of commissioning processes that are occurring internationally. While data was often difficult to obtain, the project expanded knowledge in two key areas:

1. the scope of the Cx process employed for new and existing buildings, and

2. the characterization of issues discovered through the Cx process including system type, likely origin of issue (design, construction / installation, O&M, or capital improvement), issue type, and measures implemented.

While the project results begin to develop a qualitative picture for how commissioning is evolving internationally, quantitative results were less apparent. For example, data on commissioning costs and energy savings were highly variable. Falling short of the data collection goals set by the project participating representatives, it was not possible to draw strong conclusions about the cost-effectiveness of Cx across countries. However, progress was made towards understanding and categorizing the state of the commissioning industry for new and existing buildings in project participating countries. While all countries have Cx research occurring, the majority of countries are in an early adopter phase of industry development. Only a few countries can be categorized as having a developing commissioning industry in which services are becoming more commonly obtained by owners.

For the project studies, new construction Cx costs ranged from $0.65 per m2 to $2.57 per m2 ($0.65 per ft2 to $27.66 per ft2), but the way in which costs were attributed varied. Savings values were either not reported, or considered unreliable as reference values, and so payback values were not calculated for new construction Cx in the project studies.

For existing building Cx, calculating simple payback resulted in a small data set (19 samples), but this serves to illustrate a typical range of values (see Figure 3).

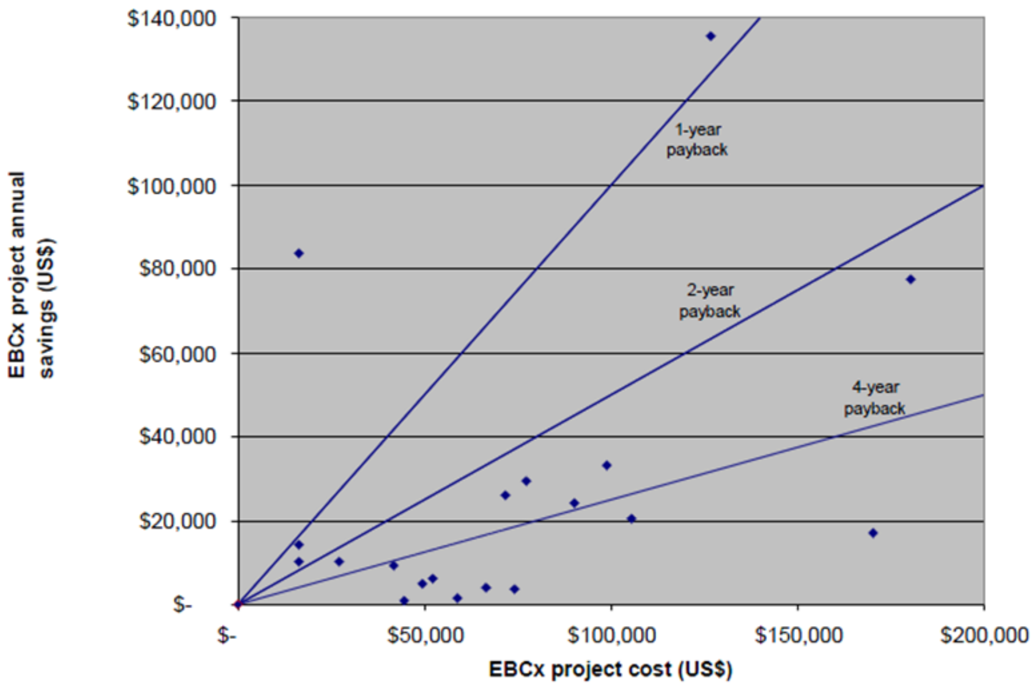
Project simple payback values ranged from 0.9 years to 45.7 years, with a median value of 3.7 years. Nine out of the 19 studies had a payback of greater than four years, and six had payback of between two and four years.

Improving Information Access through the Building Lifecycle

The project investigated the initial commissioning of advanced and low energy building systems. It focused on the concept, design, construction, acceptance, and early operation phase of buildings to see what could be improved for future buildings. It provided a state of the art description of the use of flow charts and data models in the practice and research of initial commissioning of advanced and low energy building systems. This is an area with complex data and process management needs. Without digital tools to assist in this management task, there are significant losses of information, time and money.

The vision of the future suggested by this investigation is that the commissioning agent is stationed at a console, able to access a very large portion of the data needed through data mining and sensor-control feeds; they can produce reports, recommendations, and persistent data stores, digitally and with interoperability; and share this with a variety of building professionals, including architects, design engineers, facility managers, building operators, owners and equipment manufacturers. To enable this vision, Cx data and processes must be formally

Figure 3 Costs versus annual savings estimates based on 19 studies of existing building Cx (EBCx)



represented in databases and associated algorithms in a format compatible with tools used by different practitioners and over long periods of time. Two key requirements emerging from this vision are formal representation and interoperability of information.

The findings and recommendations in the commissioning of advanced and low-energy building systems include encouraging the use of:

- Integrated Definition diagrams (IDEF, a family of methods for system design and modeling for system analysis) to provide a systematic and structured method to describe the internal information flow of a process as a shared representation by all constituents involved;

- Functional Performance Tests (FPT) and similar Cx protocol data as a testbed for commissioning flow charts and process models;

- Existing energy auditing, the "green movement," and building occupancy certification procedures as leverage to implement the purposes of commissioning;

- Available product modelling software - such as Express Language of the Industry Foundation Classes (IFC), Seadec data eXchange Format (SXF), and Green Building XML (gbXML) to represent building performance data and FPT protocols for the commissioning; and

- Conventional database representations such as ACCESS, RDBMS, HDF5 in order to formalize data representations and Flow Chart.

The final and overarching project recommendations were to move the industry towards:

- Standardizing parameters of commissioning data, users, and practices;

- Finding representations that can carry data from one phase of building delivery to the next one seamlessly, minimizing information loss;

- Partnering with the current efforts in the area of building information modeling (BIM) and developing parallel models and software applications for commissioning of advanced and low-energy buildings;

- Researching challenges of cost, function, and payback in digital Cx tools; and

- Developing historic data records for commissioning of advanced and low-energy buildings based on pre-specified data and flow chart categories.

Report 4 'Flowcharts and Data Models for Initial Commissioning of Advanced and Low Energy Building Systems' presents these findings, together with process tools.

Concluding Remarks

In many countries, commissioning is still an emerging activity and in all countries, advances are needed for greater formalization and standardization. The products of this research project are intended to promote best practices, to advance commissioning development and to serve as the basis of further research in this growing field.

Further Information

Report 1: Chloé Legris, Natascha Milesi Ferretti and Daniel Choinière, *Commissioning Overview*, National Institute of Standards and Technology, and Natural Resources Canada, 2010

Report 2: Christian Neumann, Harunori Yoshida, Daniel Choinière and Natascha Milesi Ferretti, *Commissioning Tools for Existing and Low energy Buildings*, National Institute of Standards and Technology, and Natural Resources Canada, 2010

Report 3: Hannah Friedman, David Claridge, Daniel Choinière and Natascha Milesi Ferretti, *Commissioning Cost-Benefit and Persistence of Savings*, National Institute of Standards and Technology, and Natural Resources Canada, 2010

Report 4: Ömer Akin, Natascha Milesi Ferretti, Daniel Choiniere and David Claridge, *Flow Charts and Data Models for Initial Commissioning of Advanced and Low Energy Building Systems*, National Institute of Standards and Technology, and Natural Resources Canada, 2010

Project Reports

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Czech Republic	Czech Technical University
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Germany	Ebert-Baumann Engineers, Institute of Building Services and Energy Design, Fraunhofer Institute for Solar Energy Systems ISE
Hong Kong/China	Hong Kong Polytechnic University
Hungary	University of Pécs
Japan	Kyoto University Kyushu University Chubu University Okayama University of Science NTT Facilities Osaka Gas Co. Kansai Electric Power Co. Kyushu Electric Power Co. SANKO Air Conditioning Co. Daikin Air-conditioning and Environmental Lab Tokyo Electric Power Co. Tokyo Gas Co. Takenaka Corp Chubu Electric Power Co. Tokyo Gas Co., Ltd. Tonets Corp Nikken Sekkei Ltd Hitachi Plant Technologies Mori Building Co. Takasago Thermal Engineering Co., Ltd. Institute for Building Environment and Energy Conservation

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