

The International State of Building System Commissioning

*Natascha S. Castro, National Institute of Standards and Technology
Dr. Nobuo Nakahara, Building Services Commissioning Association
Dr. Harunori Yoshida, Kyoto University*

ABSTRACT

Buildings are a major source of energy consumption and direct contributors to the significant problems associated with energy dependence and growing environmental impacts. Building system commissioning is a quality assurance process designed to improve the operations of existing buildings and the design, construction and operations of future buildings. This process is gaining support in many countries as building owners and other stakeholders see the benefits through real-world projects. More investment is needed to scale up the technology as a means to realize critical energy performance goals.

This paper presents an assessment of the international state of building system commissioning in the Asia Pacific, European and North American regions, based on 15 countries. National reports highlight a variety of initiatives that are underway. The review covers existing conditions for both new construction and existing buildings and analyzes the local and international mechanisms that are developing the market.

Introduction

Approximately one-third of the global energy use is attributed to buildings and, despite improvements in the thermal performance of buildings, is inefficiently used (ECBCS 2008). This inefficiency, coupled with concerns for energy availability and increased understanding of the environmental impact of the building sector, is raising interest in energy efficient technologies and delivery processes. However, because the buildings industry is strongly driven by first cost, investment decisions that are often made without considering payback over the building lifecycle present a barrier to improving the building stock and environmental stewardship.

Although many countries have their own established procedures for the design, construction, and operation of buildings, current approaches are inadequate for ensuring that buildings perform as intended. The complex and often opaque definitions of roles and responsibilities for members of the building industry lead to inefficiencies and information gaps in the lifecycle, even for conventional building systems. As non-conventional systems are introduced, a lack of familiarity by the designers, installers, or end-users can lead to misapplication of technologies and result in poor performance. Risk directly impacts the need for an independent quality assurance process.

Building systems commissioning is increasingly recognized as a valuable mechanism for quality assurance. The process is aligned with industry best-practices, where the roles of the individual players and their interactions are defined and the impact of their decisions can be considered. Initial commissioning begins during design and continues through construction, occupancy; it helps ensure that the performance of the new building or major retrofit meets

owner expectations. Retrocommissioning applies the same process to existing buildings with the goal of improving the integrated performance of the building systems. Recommissioning is another type of commissioning that occurs when a building that has already been commissioned undergoes another commissioning process. Most buildings experience degradation in performance that if left untreated will reduce occupant productivity and energy efficiency, often well before comfort complaints trigger a response. The process of lifetime commissioning or ongoing commissioning seeks to apply regular checks of the systems and their interactions to maintain a greater level of performance through out the lifecycle of the building.¹

The global need for improved building performance has led to numerous international collaborations. Because technological and policy developments occur at different rates and in different regions, there is an opportunity for mutual benefit and rapid advancement through the exchange of information. Two research projects under IEA's ECBCS program on commissioning, Annex 40 (2000-2005) and Annex 47 (2005-2009),² provide a forum for the exchange of knowledge and experience among participating countries. Common definitions of the commissioning process were established in Annex 40 and the research initiated under each of these projects has become the basis for the development of national guidelines.

The State of Building Systems Commissioning

Regional partnerships and international collaborations to promote the commissioning process have accelerated awareness and adoption. The following sections on the Asia Pacific, Europe, and North America regions provide an overview of the state of building systems commissioning. Each national assessment aims to present the national drivers, leading efforts and an indication of their success (if known). Fifteen countries are represented in this review.³

Asia Pacific

In the Asia Pacific region, the construction industry is experiencing unparalleled growth. China alone reports the annual construction of two billion square meters of floor space, (Qiu, 2008). The environmental impact of this growth has global repercussions. It is therefore critical that the buildings industry adopt building commissioning as a standard practice to improve the quality and efficiency of design, construction, and operations.

Asia Pacific countries are leveraging national energy laws, institutional mandates, and non-profit organizations to foster development of building systems commissioning. For several countries in the region, recent exposure through international symposia and conferences sparked interest that has developed into national research projects. This is particularly useful for countries that have natural synergies due to climate or other similarities that facilitate

¹ These definitions stem from commissioning guidelines in the USA. International definitions are varied in their scope though there are efforts to harmonize practices as will be discussed in this report.

² IEA member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States.

³ Ongoing research in Hong Kong, Czech Republic, Norway, and the Netherlands was presented in Castro 2006.

transposition of technologies or guidelines. Through these cooperative exchanges, countries are able to leapfrog technologies and accelerate adoption.

Australia: Indoor environmental quality assessments, increasing energy costs, and greater understanding of the link between comfort and productivity are driving the demand for improved energy efficiency of buildings in Australia. However, at present, most of the commissioning projects are associated with major contracts and do not address smaller projects. Furthermore, the fully integrated approach to project commissioning, promoted by CIBSE and ASHRAE commissioning guidelines, are not well understood by the commercial sector, and this educational need is yet to be addressed (EcoLibrium 2006). Awareness of the importance of the commissioning process is increasing, largely in part to the market influence of voluntary, performance-based rating schemes such as the National Australian Built Environment Rating System, and the Green Building Council's Green Star program. Through this mechanism, some large stakeholders in the property market and governmental agencies in several states have made commitments to achieve a certain rating in their building stock. The implementation and promotion of these rating schemes have the potential to trigger the demand for energy audits and commissioning in the existing building stock.

Deakin University is developing rapid reporting techniques to facilitate building performance improvement in the commissioning process (Nakahara et al. 2007).

China: Mainland China has seen several construction booms. In the 1980's the rapid growth of new residential construction prompted the Ministry of Construction to begin developing energy-efficient building codes, however, these codes did not include commissioning and quality in general was considered poor. In the 1990's, testing and commissioning concepts diffused into the Chinese buildings industry as part of the western management techniques from numerous overseas, joint venture construction projects (Chow et al. 2006). International partnerships now extend to construction projects as well as academic research. Some Chinese universities, including Tsinghua University, are conducting research on building optimization, building commissioning and other related work. Recently, in 2008, China's Ministry for Construction released acceptance codes for building services equipment and building systems and reported on energy conservation measures in China.

Hong Kong was one of the first adopters and developers of the building commissioning process due to early exposure to the United Kingdom's commissioning model. As early as 1990, the Hong Kong Government published twelve booklets based on the Chartered Institution of Building Services Engineers (CIBSE) Commissioning Codes. The documents were developed into commissioning specifications released in 2002 and are intended to be incorporated into government building project contracts (Chow, 2006). Furthermore, in 2004, Hong Kong introduced a new voluntary scheme, termed the Consolidated Environmental Performance Assessment Scheme (CEPAS), to promote the design of environmentally-friendly buildings. CEPAS incorporates building commissioning as a major element for performance assessment.

The Hong Kong Building Commissioning Centre (HKBCxC) was established in December 2004 as a non-profit organization whose mission is to promote the establishment of a standardized approach to building commissioning in Hong Kong. The HKBCxC recently published the "Practical Guide to Building Commissioning Management" which reports that independent contracts for commissioning and retro-commissioning are soaring in Hong Kong

(Chow et al., 2006). The HKBCxC organizes relevant continuing professional development programs and certification services and publishes guidebooks on the management of building commissioning, field adjustments and measurements at installations.

Japan: In 2006, performance reporting became mandatory under the Energy Conservation Law. This report is based on very simple performance testing of major components (e.g., air filters, chillers, fans and pumps, etc.) that have the largest impact on the energy consumption of heating, ventilation, and air-conditioning systems. Aspects of the commissioning process are drawing more attention in Japan's building sector. In existing buildings, various approaches for retro-commissioning are commonly implemented, but initial commissioning for new construction is not common. In 2005 the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE) technical committee on commissioning issued a guideline on the building services commissioning process.

The Building Services Commissioning Association (BSCA), a non-profit organization launched in 2004, provides seminars for commissioning technologies in major cities and has undertaken cooperative activities with Asian countries such as China (including Hong Kong), Taiwan, and Korea. It also continues to compile commissioning documentation and tools through actual commissioning projects and research. Market demand for commissioning process is believed to be strong but a mandatory trigger based on energy and environmental policy is needed for building owners to apply building commissioning for new construction. BSCA's strategy is to establish a certification program for commissioning engineers, including the Commissioning Authority, and to enlighten the audiences in construction society and related government sectors.

Energy policy is playing an important role. The Ministry of Economy, Trade and Industries is interested in a new business model, based on building commissioning, to enhance energy efficiency of new and existing buildings and the Ministry of Land, Infrastructure and Transportation is promoting use of lifecycle energy management with a newly developed simulation tool.

Taiwan: In Taiwan, building commissioning is considered established practice. The Taiwanese government has issued a mandate requiring that all public projects with budget over 15 million USD acquire the Green Building Label before a construction permit can be granted. Testing, adjusting and balancing (TAB), commissioning and the use of a BEMS are prerequisites. However, the process implemented in Taiwan does not represent the full range of actions from design to operations. The commissioning role in Taiwan for existing buildings is typically similar to that served by energy service companies in Japan and the USA. Taiwan is, however, involved in international activities to expand national practices as deemed necessary. For example, a review of the Green Building Label (similar to LEED in the U.S. and CASBEE in Japan) suggested that a commissioning system be added.

A national-scale project was launched in 2003, by the Architecture and Building Research Institute, Ministry of the Interior, to renovate all the central HVAC systems in governmental buildings for energy conservation. The renovation process includes system diagnostics, remedial strategies establishing, engineering jobs contracting, TAB and commissioning, and system performance validation through the BEMS. To date, 22 million USD budget has been spent with an overall energy-savings effect of 22 % and an average payback of 5

years. The success has since led to a whole series of demonstration projects for civil and governmental projects. In 2008, Taiwan will launch another 5 year program, phase two, where the energy savings effort will be enhanced with greater system fine-tuning and commissioning as a means to support the Kyoto Protocol and global CO₂ emission reduction efforts.

Korea: The Korean Institute for Energy Research (KIER) was an observer to the IEA ECBCS Annex 40 on Commissioning HVAC systems for Improved Energy Performance. KIER is working to promote the commissioning process by regulation of the construction industry from the viewpoint of energy conservation and quality assurance of new construction. However, at present, the Korean government has no intention to mandate the commissioning process and there is no recognized standard for the commissioning process. Commissioning projects have been carried out by KIER as part of their research work, and have also been implemented in several foreign-capital based buildings.

Europe

The countries of the European region present significant differences in their building delivery processes as well as their emphasis on energy efficiency and measures for quality assurance. For most, with the exception of the UK, the commissioning process is quite new. However, the European Commission established the European Directive 2002/91/EC (European Performance of Buildings Directive, EPBD.) to promote the improvement of energy efficiency and building performance. Four requirements to be implemented by the Member States⁴:

- Framework for a methodology to calculate the integrated performance of buildings,
- Setting of minimum standards in new and existing buildings,
- Energy Certification of Buildings, and
- Inspection and assessment of heating and cooling installations.

According to reports from the member states, the EPBD poses significant challenges in terms of its practical implementation, including difficulties associated with the transposition of requirements into existing building practices in a range of climates. However, because the commissioning process is well aligned with the goals of the EPBD, several national research programs are introducing commissioning tools as a means to address the requirements of the directive. In many countries, commissioning tasks are focused on the building handover, or as part of the facilities management, however, for commissioning to have a real impact on savings, the review must begin at the programming phase, where changes are easier and more cost-effective to make. It is anticipated that the increased attention to energy efficiency in buildings will lead to greater application and consistency of commissioning through the building lifecycle.

⁴ Member States for EPBD: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland. Norway and Croatia have also been involved in work to harmonize national procedures.

Belgium: Commissioning research has been underway in Belgium for several years, and mainstream awareness of the importance of commissioning of low-energy buildings has increased since the implementation of the EPBD and since the introduction of the passive house concept for very low energy building. Energy Performance laws, which set requirements for the energy performance and indoor climate for most buildings requiring a building permit, exist in the Flemish Region and are under development in the Brussels and Walloon regions.

Czech Republic: Building commissioning is a new concept in the Czech Republic, however, activities addressing aspects of building commissioning are implemented in the Czech Republic as a part of the facility management and energy auditing processes that are related to EPBD implementation. Researchers have developed tools that support additional aspects of the broader commissioning process, including new control system energy services.

Finland: Historically, individual contractors and builders have managed commissioning type activities as part of their quality assurance measures although, more recently, emphasis has been placed on the development and implementation of "energy auditing" procedures. In 2002, a Finnish national research program called CUBE was launched to improve the performance of building services. This program includes a national R&D project to develop Finnish procedures for building commissioning, focusing on the indoor air quality and energy efficiency of buildings. International cooperation within the framework of IEA ECBCS Annexes 36, 40 and 47 was reported to be a vital part of the project implementation.

The results of the national project include a commissioning guide book in 2006 along with the promotion of the Finnish term and concept of "toimivuuden varmistaminen (ToVa)," an adaptation of the building systems commissioning. Practical testing and further development of the guidebook and tools is underway. Methods and tools are being developed to support the commissioning of buildings and of their service systems process during different life-cycle phases.

France: The commissioning process is just beginning to take hold in France and a national guideline on commissioning is under development. In practice, commissioning is implemented in the operations phase, though there is greater interest from large building owners for more complete commissioning plans as a result of ongoing national research and new requirements under the EPBD. Current research is focused on automating the commissioning process to improve performance, pushing for early implementation of the commissioning process from design through certification, and developing tools and procedures for specific building applications (e.g., schools).

Germany: Commissioning for new construction is not established or even required as a third party service in Germany; however, some of the tasks usually required are conducted by the architects and design engineers within construction administration and construction supervision include:

- supervising acceptance and performance tests and statement of deficiencies;
- collecting/compiling and delivering as-built documentation, operating manuals, and acceptance protocols; and,

- supervising the rectification of deficiencies, up to a maximum of five years from date of acceptance.

Under a German national research program on energy optimization in buildings (ENOB), more than 20 demonstration buildings have already been built with great success, outperforming national energy consumption standards by 50 % without additional building costs. The program has been continued, supporting the design process, commissioning, and monitoring of the first two years of operation. ENOB also supports several projects focusing on improved commissioning and operation of innovative buildings. Energy agencies and utilities support energy efficiency through contracting and public private partnerships. Fraunhofer ISE and the University Braunschweig are also involved. Furthermore, Fraunhofer ISE is involved in two projects, ModBen and Building EQ, which deal with performance evaluation of existing buildings.

The Netherlands: In the Netherlands, practitioners in the field agree on the importance of building commissioning. However, it is currently only implemented in the installation and formal handover of selected buildings. A pilot project on functional performance tests conducted in 40 buildings identified that 70 % of the systems tested in were malfunctioning, leading to increased energy use and reduced comfort. To improve system operation, large-building owners are investigating new contract forms for system management and maintenance, based on well-defined performance criteria. Commissioning and the process of commissioning play an important role. The Netherlands Organization for Applied Scientific Research is involved in the development of national standards concerning the energy performance of new buildings to promote the implementation of the whole commissioning process.

Norway: Building commissioning is not established practice in Norway, however, a draft national commissioning procedure has been developed. This national guideline is currently under review and is scheduled for field testing as part of a national research project. The objective is to develop a standardized procedure for constructing, operating and maintaining the HVAC systems in order to promote the life-long commissioning of building HVAC systems. Several large governmental and private building owners are involved in the effort to verify, document and implement suitable tools to provide continuous control of energy and indoor environment during the life of the building.

United Kingdom: The UK developed the earliest commissioning codes. The first, on air-distribution systems, was published in 1960 by the Chartered Institution of Building Services Engineers (CIBSE). Subsequently, CIBSE released codes for other types of equipment. The emphasis of the commissioning codes was post-construction commissioning procedures. The current set of commissioning codes includes: Air Distribution Systems, Boilers, Automatic Controls, Lighting, Management (Code M), Refrigeration, and Water Distribution Systems. Code M shows an important change in the approach to the initial commissioning process by saying that commissioning manager is best appointed at the early stages of design phase in order for the system to be designed as commissionable.

Other non-profit organizations include the Building Services Research and Information Association (BSRIA), a consultancy test and research organization, and the Commissioning

Specialists Association (CSA) which is focused on career development and training. The development of commissioning in the UK was the basis for similar work in many other countries.

North America

The concept of building commissioning was developed relatively early in Canada, with the Code of Practice for Commissioning Mechanical Systems in Buildings authored in 1986 by the Standing Committee of Consulting Engineers and Mechanical Contractors of British Columbia. In North America there are several industry-recognized guidelines and standards on the commissioning process: American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Guideline 1-1989 The HVAC Commissioning Process (revised in 1996), and ASHRAE Guideline 0-2005, The Commissioning Process. Although building systems commissioning is established practice in both Canada and the USA, the process is not widespread. Many of the existing resources are focused on conventional HVAC systems and there is need for more information on other types of systems, particularly in light of increased interest in non-conventional, low energy systems.

Market barriers are similar in Canada and the USA and include a need for greater awareness of the benefits and cost of commissioning to grow demand, training and certification of commissioning providers to grow the supply. At present, building owners lack the access to experience and lessons learned in easily accessible, creditable and persuasive formats that would facilitate their investment decisions. Tools and standardization are also needed to reduce the cost of commissioning and improve the cost-benefit ratio for greater uptake. This includes automated tools, data on cost-benefits, and clear specifications for key building performance metrics, monitoring methods, and energy calculation methods.

In both Canada and the USA, awareness has increased through professional organizations, certification programs (e.g., LEED), large-owner mandates, and energy-efficiency initiatives. More specific national programs are described below.

Canada: Commissioning in Canada is quite limited; generally implemented as a result of large owner mandates or as a part of a green building rating program. There is, however, growing interest in developing a non-profit commissioning organization as a means to accelerate training and certification of commissioning providers and to educate stakeholders.

There are two national-scale research programs which involve the participation of governmental departments and partnerships with national energy utilities. The initiatives include the development of guides, tools and incentives that facilitate the implementation of the optimization process, as well as the delivery of training and awareness programs aimed at addressing the needs of building owners, commissioning providers and building operators. The Program of Energy Research and Development funded a project on Intelligent Building Operating Technologies and is focused on research and development. This effort runs parallel to a program from the Office of Energy that is focused on implementation and includes a project to promote the optimization process through more than 20 demonstration projects. Several of the projects implement DABO, a continuous building optimization tool developed in Canada. Demonstration projects also include some of the first Canadian Leadership in Energy and Environmental Design (LEED) buildings and involve the participation of major Canadian facility management firms and commissioning providers.

USA: Rising energy costs and a shift in public policy that emphasizes the need for energy independence is driving energy conservation. In the absence of national commissioning requirements, individual state requirements⁵ and institutional mandates have proven to be strong market drivers.

The buildings industry is working to address market barriers and improve the quality of its services. Non-profit organizations, including ASHRAE, Portland Energy Conservation, Inc. (PECI), the California Commissioning Collaborative (CCC) and the Building Commissioning Association (BCA), provide access to valuable industry resources for both providers and building owners.

- Library of published papers and Commissioning guides: retro-, initial, and on-going
- Tools: design guides, O&M best practices, case studies database
- Sample documents: Commissioning plans, specifications, functional tests, checklists
- Training and certification programs, career and provider directories

In recent years, market indicators show growth in the number of firms offering commissioning services. In 2008, 267 commissioning provider firms and 665 members registered with the BCA. There has also been a dramatic increase in commissioning certification and training provided by professional organizations⁶, which indicate a demand by engineering professionals for more knowledge.

Utilities and government agencies have also invested resources on research and technology demonstration activities in an effort to stimulate the market for commissioning. Both the demand-side growth and supply-side growth must be accelerated to significantly improve the energy efficiency of the existing building stock, to meet the low energy targets for new construction, and to address the projected shortage of skilled and certified providers.

Summary and Conclusions

Commissioning is a promising quality assurance process and is gaining acceptance internationally as a means to improve building performance. The concept of commissioning originated in the UK in the 1960's and developed in Hong Kong and Canada in the 1980's. The process has been refined in individual countries and researchers are working with the buildings industry to merge the commissioning process with existing best practices to develop a more complete and streamlined approach to ensure that buildings operate as intended.

This paper reviewed the state of commissioning in 15 countries within the Asia Pacific, European, and North American regions. For the buildings industry, the need for improved energy efficiency and quality assurance has long been evident, but shortsighted investment

⁵ California set requirements for acceptance testing, Washington state building code includes requirements for lighting controls and mechanical systems and Massachusetts has approval and acceptance requirements in the energy conservation section of its building code.

⁶ Certification and Training Providers include: BCA / University of Wisconsin, National Environmental Balancing Bureau (NEBB), Associate Air Balance Council (AABC), Association of Energy Engineers (AEE), Sheet Metal and Air Conditioning Contractors National Council (SMACNA), ASHRAE, and PECI

criteria and decisions present a major barrier. In recent years, rising energy consumption in buildings and greater awareness of their energy impact has prompted both national and international concerns regarding energy security and environmental security. Furthermore, much of the information on potential energy savings or cost savings through commissioning is anecdotal. There is an immediate need for research to establish standard methodologies to document these costs and benefits.

International programs provided the basis for technology transfer and policy adoption. In the area of commissioning, this includes the IEA ECBCS Annex 40 and Annex 47 research projects, the international dissemination of commissioning information lead by national commissioning non-profit organizations, and individual commissioning projects. As a result of these interactions, individual countries have adopted similar strategies to improve their existing building stock and new construction.

Early investors in the commissioning process have attempted a number of different development paths including national research programs, development of guidelines, government 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 the typical anecdotal reports) exists in every country reviewed in this assessment. Demonstration projects have provided a foothold for the industry which in turn justifies the greater measures, large owner mandates, national mandates that are needed to scale up the technology and its adoption as standard practice.

The dissemination of information and education is also a critical component in establishing the commissioning process. Non-profit organizations including the BSCA, CIBSE, HKBCxC, and PECEI have each 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 green house gases are gaining political support, investment still lags behind. There is a disparity between those who must invest in commissioning technology development and those who benefit, therefore adoption has been slow and drivers are needed to grow both on 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, to greatly increase the number of skilled providers, and to provide them with the resources that will enable the industry to scale up the technology to meet national and international needs. On the demand side, education is needed for owners to see the long-term benefits, and the resources to make the business case for the investment, and contracting documents to procure commissioning services. Harmonization is needed to assure that the process adequately spans the building lifecycle for improved energy performance and that the benefits that have been 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.

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References

- Castro, N. and D. Choinière. 2006. Cost-Effective Commissioning for Existing and Low Energy Buildings- A New IEA ECBCS Research Project. Proceedings of the National Conference on Building Commissioning.
- Chow, L. KH. et al. 2006. Practice Guide to Building Commissioning Management. Hong Kong Building Commissioning Centre.
- EcoLibrium. 2006. Commissioning: where to now? Australian Institute of Refrigeration, Air-conditioning and Heating, June edition.
- European Commission, 2002. *European Performance of Buildings Directive*. European Directive 2002/91/EC.
- International Energy Agency. 2008. Energy Conservation in Building and Community Systems Work Program, www.iea.org <http://www.ecbcs.org/home.htm>
- Nakahara, N. et al. 2007. Proceedings of the Asia Pacific Conference on Building Commissioning (APCBC) Workshop in Kyoto, Japan.
- Nakahara, N. 2004. Japanese Vision Of Commissioning Process And Asian View. Proceedings of the International Conference on Enhance Building Operations.

Qiu Baoxing, 2008. *Press briefing on China's energy-efficient building and green building initiative*, Feb. 26, 2008. http://english.gov.cn/2008-02/28/content_904034.htm

Visier, J.C. et al. 2005. IEA Annex 40: Commissioning of Buildings and HVAC Systems for Improved Energy Performance. Final report, www.commissioning-hvac.org

