Natural Resources Canada
Ressources naturelles Canada

CETC-Varennes

Clean Energy Technologies

Business Case

A Climate Change Solution

Intelligent Building Operating Technologies

A Cost-Effective Reduction in Building Energy Consumption

Second Edition
May 2004

Canada

We would appreciate hearing from you about this document. Please send your comments to:

CANMET Energy Technology Centre - Varennes

1615, Lionel-Boulet Boulevard, P.O. Box 4800
Varennes, Quebec J3X 1S6
Canada

Facsimile: 1 (450) 652-5177
Email: CTEC-CETC.Varennes@NRCan.gc.ca

For more information:

Telephone: 1 (450) 652-4621
Facsimile: 1 (450) 652-5177
Website: http://cetc-varennes.nrcan.gc.ca

Le document est aussi disponible en français sous le titre : Technologies d'opération de bâtiments intelligents, une solution rentable permettant de réduire la consommation énergétique dans les bâtiments

ISBN: 0-662-36660-3

Catalogue no.: M39-103/2004E-PDF

Business Case

A Climate Change Solution

Intelligent Building Operating Technologies

A Cost-Effective Reduction in Building Energy Consumption

Second Edition
May 2004

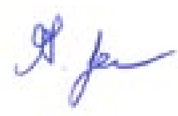
FOREWORD

For more than two decades energy has been taken for granted. Recent events such as the major black-out in the US and Canada; the increase of fossil fuel energy costs and the ice storm in Quebec as well as other climatic events that lent credibility to climate change, have brought energy back at the top of the public agenda. Given the important role energy plays in our quality of life and its impact on the economy, it is not surprising to see energy arising as a key issue. With it comes a renewed interest in energy efficiency.

According to the general wisdom, decreasing our energy consumption and the associated greenhouse gas emissions (GHG) will require a change in life style or major investments in more efficient but more expensive technologies. Some may be surprised to learn that simply improving the way we maintain and operate commercial and institutional buildings can decrease their energy consumption by as much as 20%, and sometimes even more. What is even more surprising is to learn that the simple payback to get those savings is about one year.

The prevalent practice in the building industry is to spend the minimum on operation and maintenance. The result of this approach is that most buildings have problems that are unknown to the operator. And there is no easy way to identify them. This leads to the vicious cycle where building operators are not aware of problems that waste energy, consequently nothing is done to correct them.

In this document, we propose an efficient solution to break this vicious cycle: the use of **Intelligent Building Operating Technologies** to continuously diagnose equipment problems, provide performance reports and allow the operator to optimize the operation of the building. Our hope is that this document will contribute to increasing the aware ness of building owners and other stakeholders to this opportunity and will eventually lead to the establishment of a national retro-commissioning program to improve building operation in Canada.



Dr. Gilles Jean
Director
CANMET Energy Technology Centre - Varennes

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Energy consumption in the Commercial and Institutional (C&I) building sector represents approximately 13% of secondary energy consumed in Canada, and contributes roughly the same proportion of greenhouse gas (GHG) emissions (61 Mt equivalent CO_2 in 2001) [6] . The energy consumption of this sector could be reduced if the operation of the buildings were improved. Most buildings have equipment and system problems that are unknown to the operator. This leads to a waste of approximately 20% of the energy consumed in the C&I building sector. The problem so far had been that there was no easy way to correct the situation. The CANMET Energy Technology Centre - Varennes (CETC-Varennes) is proposing the use of **Intelligent Building Operating Technologies** to tackle this problem.

The **Intelligent Building Operating Technologies** is a set of software solutions utilizing artificial intelligence algorithms that can work with most existing building energy management control systems to continuously diagnose equipment and system problems, provide performance reports and allow the operator to optimize the operation of the building. These software solutions, combined with retro-commissioning, a systematic approach to correcting equipment and system problems and to re-evaluating control strategies, can be deployed to approximately 60% of the overall building surface area in Canada. The implementation of this approach is estimated to result in an annual energy savings potential equivalent to 14 TWh of electricity and 1.5 billion m^3 of natural gas. These savings correspond to \$1.8 billion and 7 Mt of GHG emissions per year for the Canadian C&I building sector.

The establishment of a national retro-commissioning program would act as a catalyst to the implementation of this approach. It would eliminate the barriers to improve building operation and facilitate the continuation of the R&D aimed at completing the development of the set of **Intelligent Building Operating Technologies**.

INTRODUCTION

The amount of energy a building will consume over its lifetime is determined at the design phase, where choices regarding its systems are made and on how the building is operated and maintained. Much attention has been given to energy efficiency measures such as lighting, windows, and equipment. However, little attention has been given to ongoing building operation and maintenance.

A significant amount of the energy consumed in the Commercial and Institutional (C&I) building sector is wasted because of poor building operation. For instance, a study of fifty-one schools in Ontario found that 50 had either maintenance or systems-related problems [1]. Another study in the United States, found that more than half of the 60 commercial buildings evaluated had control problems and 40% had equipment problems [2]. This situation is the norm rather than the exception. The net result is that buildings consume between 5 and 30% more energy than they would if they were operating properly.

The impact on productivity is even more important. Each year, millions of dollars are lost due to high absenteeism and low productivity caused by poor working environments. A study reported that good indoor air quality could have a 0.25% impact in productivity, or $90/person per year [3]. As the Canadian C&I sector employs 4,794,800 people [4], $90/person per year is equivalent to $430 million in savings per year.

This document describes the potential impact that the introduction of **Intelligent Building Operating Technologies**, a set of software solutions that can ***continuously*** diagnose equipment problems and provide the operator with performance reports, could have in reducing the energy consumption in the C&I building sector. The diagnostic component is ready for deployment and could yield si-gnificant reduction in energy consumption.

1. A TECHNOLOGICAL OPPORTUNITY

Building operation seems to be a continuous, relatively homogenous activity ensuring that the building is fulfilling its purpose: providing a safe, comfortable and hopefully productive environment for its occupants, while maintaining a positive cash flow for the owner. However when one observes what building operation involves (Figure 1), it becomes clear that the operation of the building over its life, can be broken down into:

- The initial commissioning to ensure that the equipment is performing according to the specifications.
- The operation of the building's HVAC equipment using the control system.
- The fault detection which is rudimentary, generally limited to fault alarms.
- The maintenance, limited to the repair or replacement of faulty equipment.
- The retro-commissioning, a rarely used systematic process to identify and correct equipment problems and re-evaluate the control strategies.
- The continuous commissioning.

The prevalent practice in the industry is to spend the minimum possible on the operation of the building. Since the financial impact of only doing the bare minimum in operation and maintenance is unknown to building managers and owners there is no incentive to change.

Building owners and managers spend the bare minimum on building operation and maintenance. Since they are unaware of the amount of money and energy that is wasted there is no incentive to change.

Presently, there is no way to obtain a report on the performance of the building.

Two reasons explain why such a waste can go unnoticed. First, building managers and owners cannot obtain a proper performance evaluation of the building. Second, so far, there has been no easy way to identify equipment problems e.g. to perform the fault detection activities. It is possible to evaluate the performance of the building, to identify equipment problems and re-evaluate the operation strategies by performing what is known as retro-commissioning.

Commissioning and retro-commissioning are the processes of systematically identifying and correcting building problems and optimizing their operation in new and existing buildings respectively. Despite convincing arguments [5] regarding the benefits of retro-commissioning, widespread industry adoption has not occurred. Limited knowledge by owners of the direct and indirect benefits of a well-operated building, a lack of understanding of retro-commissioning and no assurances that the benefits will last could explain this. Since there is no awareness of waste of energy occurring in day-to-day operations, there is no incentive to do more. As a result, retro-commissioning is rarely employed.

The solution: use artificial intelligence to perform fault detection and performance evaluation on a continuous basis.

The CANMET Energy Technology Centre - Varennes (CETC-Varennes) is proposing the use of a set of **Intelligent Building Operating Technologies** to continuously perform fault detection and performance evaluation. The proposed technologies are a set of software solutions based on artificial intelligence algorithms developed by CETC-Varennes and introduced under the trade name DABO™. DABO™ stores and analyzes the information produced by the sensors used to control the building and continuously diagnoses problems, monitors and optimizes the performance of the building and its systems. It provides the operator with accurate reports on all aspects of the building operation as shown in Figure 1, and described below. DABO™ is the platform that will help integrate the different agents. The next section describes the various components of DABO™.

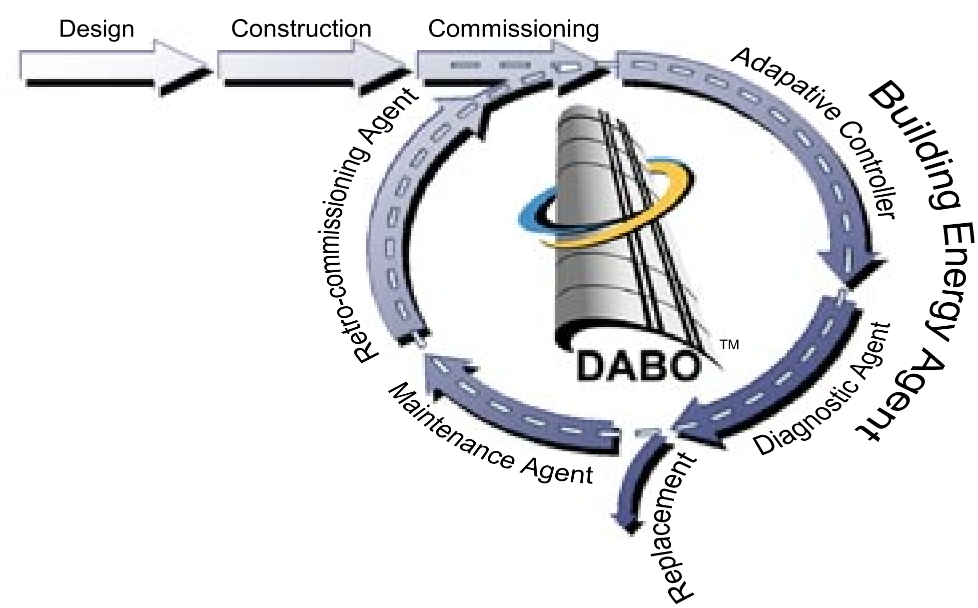


Figure 1: Intelligent Building Operating Technologies

Diagnostic Agent

The brain of the system is the ***Diagnostic Agent***. The first task of the ***Diagnostic Agent*** is to detect and diagnose equipment problems. Analyzing the information from the sensors, it provides the operator with performance reports, identifies equipment problems and details probable causes of the problems. The second task of the ***Diagnostic Agent*** is to recommend specific maintenance actions. Using the record of detected problems, the ***Diagnostic Agent*** can evaluate the state of each piece of equipment in the building. Therefore, it can provide the ***Building Maintenance Agent*** with specific maintenance recommendations.

The Diagnostic Agent is available and ready for commercialisation. This module does not require the other modules to operate. The other modules, however, will be required to ensure that the benefits last and the optimisation of the building operation.

Adaptive Controller

The second generation of control systems do more than maintain temperature, humidity and pressure set points. The ***Adaptive Controller*** will provide basic fault detection and diagnosis to the individual sub-systems, such as terminal devices and air handling units, and continously optimize their use. The ***Adaptive Controller*** will be a combination of hardware and software. This component will only be available in about three to five years.

Building Energy Agent

The ***Building Energy Agen***t supervises the actions of the ***Adaptive Controller*** and the ***Diagnostic Agent***. It uses measurements of the outdoor conditions and building energy systems, given by the ***Adaptive Controller*** and the ***Diagnostic Agent***, to predict the building's performance. Furthermore, this monitoring and predictions are used to modulate the set points of the building's HVAC systems to minimize energy consumption and demand costs. This module will also be available in about three years.

Building Maintenance Agent

The ***Building Maintenance Agent*** receives input from the ***Diagnostic Agent*** and has access to preventive maintenance schedules. It issues reports requesting maintenance services based on an optimization of the benefit of maintaining versus its cost. This module will be complete within the next twelve months.

Building Commissioning Agent

The ***Building Commissioning Agent*** initially provides the link between the design phase and the operation phase, and thereafter continuously monitors and commissions the performance of the building and its systems. It uses a library of tests to verify the performance of the sub-systems as well as of the building as a whole. This agent works seamlessly with the ***Diagnostic Agent*** and communicates through the database with the ***Building Energy Agent*** to ensure that the operation of the system is optimized. This module will be complete within the next twelve months.

The implementation of the **Intelligent Building Operating Technologies** requires the presence of a Building Energy Management System (BEMS). BEMS are computer systems that control the building mechanical and electrical systems and are currently present in the majority of buildings more than 50,000 ft^2. The **Intelligent Building Operating Technologies** use the BEMS sensors, consequently there is no need for additional hardware investment in implementing them.

2. IMPACT ASSESSMENT

In 2001, the C&I building sector in Canada accounted for 13% of secondary energy use and 13% of the greenhouse gas emissions (GHG) [6]. Retail and office space account for nearly half of the energy demand in the C&I building sector. Schools, medical institutions, hotels and restaurants account for another 34% of energy demand.

Energy consumption in the building sector will keep increasing by 1% per year.

Between 1990 and 1997, energy use in the C&I building sector increased by 13% as a result of growth in economic activity (Figure 2) [7]. From 1995 to 2020 the energy consumption in C&I building is expected to increase by 1% per year. It is therefore important to stimulate the adoption of new measures that can significantly reduce energy consumption in that sector.

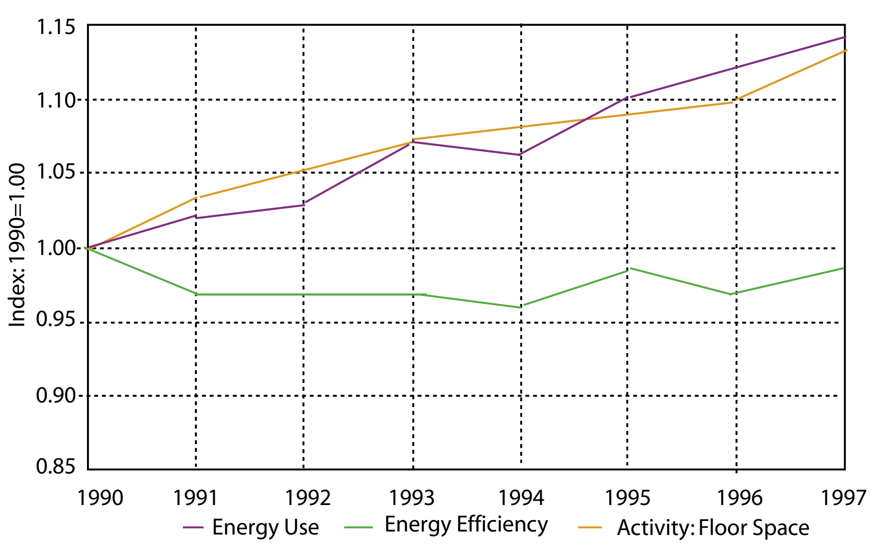


Figure 2: C&I Energy Use, Energy Efficiency and Floor Space 1990-1997 [7]

Figure 2 shows that existing energy efficiency measures have contributed to lowering the final energy consumption but that these measures cannot compensate for the increase in activity. Furthermore, the gains in energy efficiency seem to have stabilized at around 1.8% since the early 1990's. Improvements in building operation represent the best opportunity to decrease energy consumption in a cost effective way.

Several studies show that improving building operation, through what is known as retro-commissioning (without the advanced tools proposed in this document), yields efficiency improvements of 5% to 30%. Retro-commissioning is presently done manually: a specialist interviews people, examines the state of the HVAC systems with the operator and does an evaluation to identify equipment problems. This approach yields immediate and significant benefits as shown in Table 2, the average energy savings being 15.7%. However, after the retro-commissioning is completed and the team has left, the problems eventually return and the performance of the building deteriorates again.

Table 2 – Examples of Cost and Energy Savings Resulting From Building Retro-commissioning [8]

Building	Area	Ending Date	Energy Cost	Retro-commissioning Cost		Energy Cost Savings		Simple Payback
	ft^2		$\$/ft^2/yr$	Total $	$\$/ft^2$	$/yr	% of Total Cost	years
Office	80,000	1995	0.88	14,546	0.18	16,194	10.4	0.9
Office	623,000	1995	1.28	80,000	0.30	150,000	18.8	0.5
Office	470,000	1993	1.24	28,000	0.06	30,385	5.2	0.9
Office	169,756	1996	1.56	24,000	0.14	50,680	19.2	0.5
Office	592,781	1996	0.84	28,000	0.05	89,758	18.0	0.3
Library	120,000	1996	0.37	24,000	0.20	9,867	22.5	2.4
Medical Institution	887,187	1994	3.16	28,000	0.03	879,101	31.4	0
Retail	122,000	1995	0.88	11,310	0.09	13,779	12.8	0.8
Retail	107,000	1995	2.40	12,801	0.12	8,042	3.1	1.6

The tools proposed in this document will increase the energy savings related to a standard retro-commissioning. More importantly, these tools will ensure that the benefits last. They facilitate the identification of equipment problems and help an operator to continuously monitor and optimize the building operation.

Potential Impact

The impact of the **Intelligent Building Operating Technologies** will depend on two factors: the number of buildings that can be retro-commissioned and the benefits from the use of the technology that can be realistically obtained.

The global impact will depend on the number of buildings equipped with BEMS.

The use of the tools requires a central BEMS that is not found in every building. Surprisingly, there is little statistical information on the number of buildings equipped with BEMS. Discussions with major manufacturers of BEMS suggest that buildings equipped with BEMS account for about 60% floor space in Canada. This is the target estimate used for this analysis. Since this is a "best-guess" estimate, the real potential may vary significantly from this number.

The impact for each building will depend on its actual state.

The second factor, determining the real impact that is feasible is the percentage of energy that can be saved. Past experience described in the above table shows a wide range of results. Each building is different and the ultimate energy savings will depend on the state of those buildings. There is at the present time no easy way to determine with precision the average energy savings that will be obtained.

Figure 3 shows the result obtained at CETC-Varennes' own building. The implementation of the tool, followed by the correction of the identified problems and changes in the operation strategies have led to a decrease in energy consumption of more than 30%.

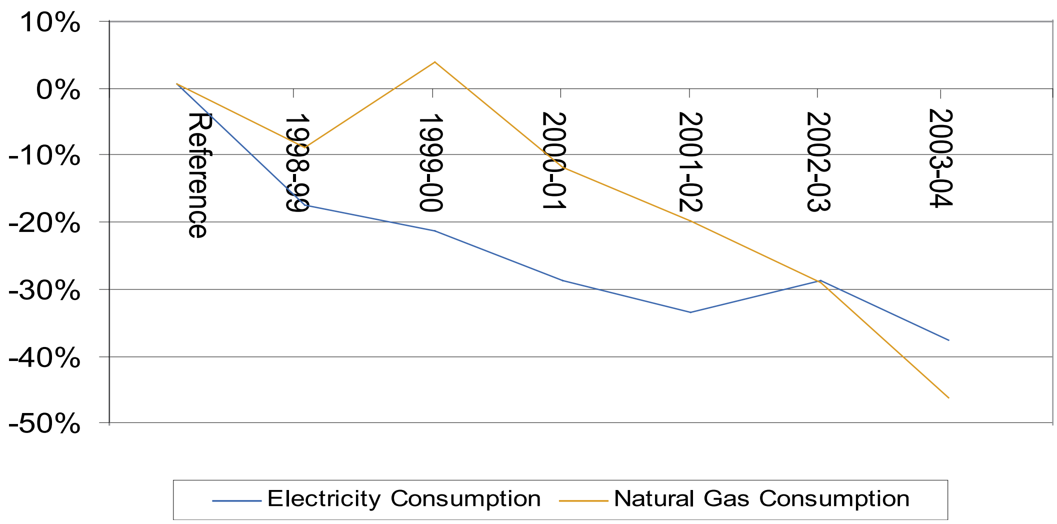


Figure 3: Impact of Retro-commissioning at CETC-Varennes

We believe that the **Intelligent Building Operating Technologies** will yield better results than the traditional retro-commissioning. Since the objective of this analysis is to get an idea of the **maximum total potential**, an energy consumption reduction of 20% is used. Therefore, if 60% of the surface area of Canada's building stock were "retro-commissionable" yielding a 20% savings of the total energy consumed, the net savings for C&I building in Canada could be 12%. The energy savings potential impact presented below has therefore been calculated assuming a 12% reduction of total energy consumption and of the associated GHG emissions.

The data published in *Energy Use Data Handbook, 1990 and 1995 to 2001*, Office of Energy Efficiency, 2003 are used to evaluate the potential impact of improving building operation [6]. The results are presented in Tables 3 and 4.

Table 3. Energy and Greenhouse Gas Savings for the Retro-commissioning Based on 2001 Data [6]

Energy Source	Energy Consumption (PJ)	Energy Savings (PJ)	Total GHG Savings (Mt)	GHG Reductions (Mt)
Electricity	444.6	53.4	28.8	3.46
Natural Gas	481.7	57.8	24.1	2.89
Fuel Oil and Kerosene	63.6	7.6	4.7	0.56
Heavy Fuel Oil	26.8	3.2	2.0	0.24
Propane	36.4	4.4	2.2	0.26
Other	0.6	0.1	0.0	0.0
Total	**1,053.7**	**126.4**	**61.8**	**7.42**

Table 4. Energy and Dollar Savings for Retro-commissioning [6]

Province	Electricity (TWh)	Natural Gas (billion m^3)	Savings ($ million)
British Columbia	1.69	0.18	158
Alberta	1.56	0.26	203
Saskatchewan	0.50	0.09	75
Manitoba	0.47	0.09	63
Ontario	5.75	0.70	800
Quebec	3.90	0.20	440
Atlantic	1.00	0.00	100
Total	**14.87**	**1.52**	**1,839**

Conversion factors used:

Electricity: - 3.6 MJ/kWh
Natural Gas: - 37.5 MJ/m^3
Electricity Costs: - 0.09 $/kWh
Natural Gas Costs: - 0.30 $/$m^3$

A total of about 15 TWh of electricity, 1.5 billion cubic meters of natural gas and more than 7 Mt eq. of CO_2 per year would be saved assuming that the impact would be proportional on all energy types used in a building. This is however unlikely and we would expect to have more impact on heating. Since natural gas is used more extensively for heating than electricity, the amount of natural gas saved is probably underestimated and the amount of electricity saved overestimated.

These energy savings would decrease the energy bill of Canadians by $1.8 billion a year. Since the payback on the investment required to retro-commission a building is typically one year, these tools would lead to a significant reduction in GHG emissions in a very cost effective way.

Table 5: Annual Potential Savings from Implementation of Retro-commissioning in Canada

Electricity (TWh)	Natural Gas (billion m^3)	GHG (Mt eq CO_2)	Savings ($ billion)
15	1.3	7.4	1.8

CONCLUSION AND RECOMMENDATIONS

The analysis presented in this document clearly indicates that improving building operation can significantly decrease the energy consumption in commercial and institutional buildings. In spite of the demonstrated benefits of improving building operation this practice has never been widely accepted. A number of reasons explain this situation.

First, building owners and managers are unsure of two important factors: is it possible to get these benefits for any building or are they representative of buildings that were in a poor state to begin with; and second, will the benefits last once the team of experts has left the building? Without a clear answer to these questions it is obvious that few managers will reach in their pockets to pull $50,000 dollars to do a retro-commissioning study. Understanding this is crucial in appreciating the importance DABO™ will play in changing this situation.

The best way to convince building owners and managers of the benefits of improving building operation is to work with them to demonstrate the methodology and the tools and to transfer the know-how to them. We therefore suggest a series of demonstrations with major firms managing and operating buildings. These demonstrations must be done by people using a proven methodology. In that respect we will develop a prescriptive approach that will ensure the success of every project.

The second key issue to address concerns the question of whether or not the results can last. This is where DABO™ comes into play.

DABO™ is an expert system that significantly facilitates the whole retro-commissioning process. DABO™ will:

- Do most of the upfront data acquisition and analysis that used to be done by the team of experts. Thus, DABO™ will perform the up-front analysis much cheaper and even better because of the intrinsic capabilities of the tool.

- With DABO™'s analytical capabilities, the building operator will begin to understand the behaviour of the building and will be empowered to make key decisions. DABO™ will in effect transfer key knowledge that was before the realm of the engineers and other experts.

- Finally, but most importantly, DABO™, as opposed to the team of experts, is there to stay. DABO™ will establish a baseline for the performance of the building and will continuously monitor and report. It is this continuous monitoring that will ensure that the results will last.

In summary, DABO™ will ensure that the results last and that improving the building operation is not a one-time exercise but rather a continuous process. The key to accomplishing this is to empower the operator with quality information. Armed with a performance report, building managers, owners and operators will know exactly how their building is performing. It will then be easy to see how the impact of this performance on the operating costs.

A good demonstration, accompanied with proper information dissemination activities will increase the awareness of the potential savings that retro-commissioning, facilitated by DABO™, offers and will convince stakeholders of the cost effectiveness of the approach. It will not however eliminate all the barriers to a widespread adoption of retro-commissioning. A national deployment program could be developed to address them.

It will also be important to continue the development of tools. DABO™ as it stands is ready for deployment and will allow Canadians to immediately capture the potential benefits derived from a better operation of their buildings. However, this is only the first generation and much remains to be done to reach the full potential of the tool.

References

1. Tamblyn, B. 1992. Commissioning: An operation and maintenance perspective. *ASHRAE Journal*. (7)10.

2. Piette, Mary Ann. 1994. Quantifying Energy Savings from Commissio-ning: Preliminary Results from the Northwest. 4th National Conference on Building Commissioning.

3. Turner, F. 1998. IAQ and Energy. *ASHRAE Journal*. (40)12.

4. Trimmel, F. et al. 1998. Foundation paper on the commercial/institutional sector in Canada. Prepared for Buildings Table, National Climate Change Secretariat.

5. Parks, Jetal. 2003. Case Studies from SMUD Retro-Commis-sio-ning Program. 11th National Conference on Building Commissioning.

6. Office of Energy Efficiency. 2003. *Energy Use Data Handbook, 1990 and 1995 to 2001*.

7. Office of Energy Efficiency. 2000. *Energy in Canada 2000*.

8. Haasl, T and Sharp, T. 1999. A Practical Guide for Commissioning Existing Buildings. Office of Building Technology, USDOE. (data extracted from pp. 10-14)

Glossary

Building Energy Management System (BEMS)

Automatic system used for controlling equipment in a building. Most likely, this will be a computer-based system including either pneumatic or digital controllers.

Commercial and Institutional buildings

Office buildings, hotels/motels, retail buildings, schools, medical institutions, ice rinks and multi-unit residential buildings.

Commissioning

Process of ensuring that systems on new construction projects are installed, functionally tested, and capable of being operated and maintained according to the original design intent and the owner's operational needs.

Continuous Commissioning

Process of commissioning on a c ontinuous basis

Retro-commissioning

A systematic investigation process to optimize an existing building's performance. Typical tasks are identifying and implementing relatively low-cost operational and maintenance improvements.

Secondary Energy Use

Energy used by final consumers for residential, agricultural, commercial, industrial and transportation purposes.

The CANMET Energy Technology Centre–Varennes (CETC–Varennes) is one of three research and innovation centres of Natural Resources Canada (NRCan). CETC-Varennes designs and implements technological solutions, and disseminates knowledge in order to produce and use energy in ways that are more efficient and sustainable, to reduce greenhouse gas (GHG) emissions, and to improve innovation capabilities of targeted sectors of the Canadian economy.

Printed on paper containing 20% recycled fibers. Recyclable, where recycling facilities are available.

CANMET Energy Technology Centre - Varennes
1615, Lionel-Boulet Blvd., P.O. Box 4800, Quebec, J3X 1S6, Canada
Telephone: (450) 652-4621, Facsimile: (450) 652-5177, Web Site: http://cetc-varennes.nrcan.gc.ca

2004-044 (PROMO)

Natural Resources Canada / Ressources naturelles Canada

Canada