REAL-WORLD INTEGRATED DESIGN PRACTICE AND TOOLS: EFFECTIVE ENERGY PERFORMANCE ANALYSIS APPROACHES

Graham Henderson, P.Eng.
BC Hydro
Burnaby, British Columbia
graham.henderson@bchydro.bc.ca

Curt Hepting, P.Eng. and Diane Ehret
EnerSys Analytics Inc.
Coquitlam, British Columbia
enersys@telus.net

ABSTRACT

To help design teams investigate energy-efficiency opportunities in the early design stages, BC Hydro conducts "Energy Performance Workshops." The workshops act as a key component of an integrated design process by providing energy simulations, integrated design workshop facilitation, and Commercial Building Incentive Program verification. The resulting building designs are both cost effective and energy efficient.

This paper discusses the EPW concept within the framework of the integrated design process. It discusses both qualitative and quantitative lessons by providing insights on the successful components of the EPW format, as well as an overview of which energy efficiency measures we consistently have found to be most cost effective. Finally, we present program results to date.

INTRODUCTION

What answer might a building owner expect from their design team if the owner asked the question “Did you design me an energy efficient building?” The answer, of course, would be a resounding “Yes!” It would be somewhat akin to the building owner asking the design team if the building would continue to stand after being constructed. No design team would provide a negative response to such a “motherhood and apple pie” sort of question. The difference in the acuity of these two responses is that the building is entirely likely to stand after being constructed, and there would be ample visual evidence to the contrary if it did not. The same, unfortunately, cannot be said for energy efficiency.

A prudent building owner who actually was concerned with ongoing operating costs, and who had just received the obligatory answer to the aforementioned energy efficiency question, would be well advised to ask the design team on what basis they staked their answer. The owner would be further well advised to reject out of hand such answers that suggest the building must be energy efficient, because either 1) we designed this building exactly like we designed the last building, and it was energy efficient, or 2) because we used a vast array of energy-efficient technologies.

The building owner should reject the first response because there is a notorious discontinuity between estimates of a building’s energy performance during design, and the actual building’s energy performance. As well, follow up regarding a building’s energy performance simply does not happen (in our juris diction and experience). Not only does it not happen regularly, it does not happen at all. Thus, there is no basis for determining that an “energy efficient” building had been built.

The building owner should reject the second response because, as will be discussed in this paper, there is a significant amount of misinformation currently existing in the market place regarding which technologies are required to make a truly energy efficient building. The net effect of this unfortunate situation is that any designer is able to say they have designed an energy-efficient building because the chances they will be proven otherwise are negligible. The chances that they will be held accountable are non-existent. What, then, is a conscientious building owner to do?

It was partly in response to this situation that BC Hydro developed its Design Assistance program, whose primary objective is to assist commercial building owners address the issue of cost-effective design from an energy performance perspective. The Design Assistance program has three primary components:

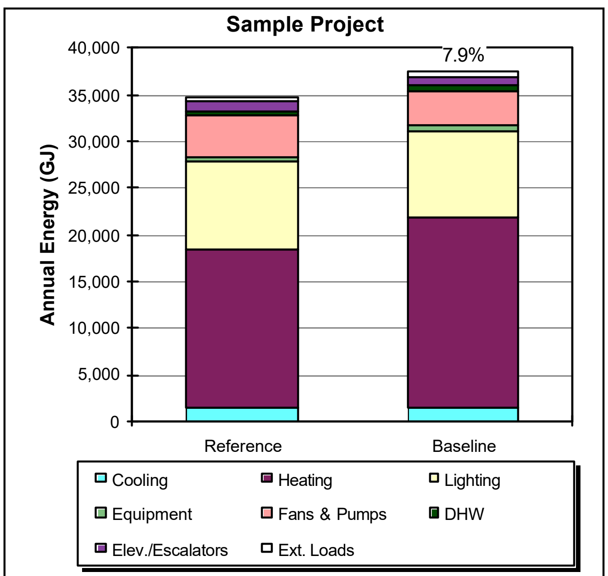
1) building energy modelling and analysis,
2) facilitating an integrated design session, and
3) completing the application and providing verification for the Commercial Building Incentive Program (CBIP).

The program contains technical and process-oriented aspects. The technical aspect has to do with the provision of quality computer simulation, provided at relatively low cost, early on in the design cycle. The process-oriented aspect has to do with providing the results of the computer simulation in a context that enhances and complements the team's integrated design efforts.

ENERGY PERFORMANCE WORKSHOP

The integrated design session, called the Energy Performance Workshop, is the key deliverable in the program. The workshop typically begins in the morning, and carries on until the early afternoon. In the workshop, we use three terms to discuss the building energy models. The "Reference" building is the CBIP-compliant building that just meets the Model National Energy Code. The "Proposed" building is the design team's current building design. The "Baseline" building is the Proposed building at the beginning of the workshop, without any of the energy efficiency measures proposed by the design team that would typically exceed standard practice (those items are modelled, but are left out of the baseline analysis, and are "tested" later according to a life-cycle costing analysis). It is from the Baseline building that all energy efficiency measures are tested. The design team is presented with the following energy end-use breakout graph of their project at the beginning of the workshop (Figure 1).

Figure 1. Sample Pre-Workshop Results



Percentage denotes savings relative to the appropriate CBIP Reference case.

The workshop itself has three ingredients which contribute to its success. The first ingredient is the presence of all interested parties in the design process. At a minimum, this must include the architect, mechanical and electrical consultants, and someone who can address the issue of capital costs (this may be either the consultants, contractors, or quantity surveyors). Additional attendees may include the owner or owner's representatives, and/or personnel from the maintenance department.

The second ingredient is the simulation software. Our process uses an in-house tool called the Building Energy Simulation Tool (BEST), which is an in-house, specialized front-end to the DOE2.1e energy performance simulation program. BEST minimizes set up time for energy simulation, presents results in an easy-to-understand format, and applies a calculational approach which taps into the results from hundreds of detailed hourly simulations. More specifically, the tool makes use of response factors produced from performing dozens of simulations on a specific building project. Each simulation represents a discrete change to a building characteristic (roof insulation, for instance). By also applying the engineering principles of how the discrete change affects energy use, the tool can calculate the end-use impacts from changing a building characteristic by nearly any amount. The approach is similar to that used by Natural Resources Canada's CBIP web screening tool (Hepting et al., 2000), and the results agree very closely with the full DOE2 simulations (Hepting 1996; Hepting and Ehret, 1998).

Using this approach, measures which have a continuum of possible values (e.g. insulation, efficiency, power density, glazing characteristics, overhangs), and are determined to be important to energy use or have been identified by the design team to have special significance are "connected" in the BEST software. We can then manipulate the characteristics as required by the design team at the time of the workshop to quantify the impact of any change on annual energy cost. On the other hand, issues that have discrete values or outcomes (e.g. schedules, mechanical systems, building form, zoning) must be coordinated in advance of the workshop, and cannot be handled ad hoc.

The advantage of using BEST is that it provides for quick feedback, which is important in a workshop setting. Moreover, it presents the results by providing instantaneous comparisons to baseline and reference cases. It also provides for peak load reduction estimates, which may affect HVAC sizing and costing. Coupled with its ability to perform life-cycle costing, the design team is able to make informed decisions that often lead to design changes *during the course of the workshop*.

The third ingredient leading to success is the fact that an energy target is set and referenced constantly throughout the workshop. During the early stages of the program (before CBIP), an appropriate ASHRAE 90.1-1989 "energy cost budget reference" provided an energy target. Now, the CBIP Reference building provides the basis for the target. The CBIP program requires that the Proposed building be shown to use 25% less energy than the Reference building in order to attain an incentive. During the workshop, the team is able to continually view their progress against the required energy target as various measures are introduced.

The typical agenda for a workshop includes an overview of the BC Hydro Design Assistance program, followed by a relatively high level review of the assumptions used in modelling the Proposed building. If changes are required based on feedback from the design team, the changes can often be incorporated on the spot. Other issues requiring discussion are economic factors, such as the discount rate or the escalation rate of utility costs, used in the life-cycle costing analysis.

After this introduction, the rest of the session is spent reviewing how cost and energy results change by altering various design parameters. For example, the architect may be interested in exploring alternative window types. This may include changes to either the U-value or the shading coefficient. Once the alternative window values are entered into the BEST program, the change in operating cost is calculated in a matter of seconds. The design team provides the marginal capital cost of the measure, as well as the impact on maintenance costs, and the payback of the measure is calculated. At the same time, the design team is able to see the sensitivity of operating costs to changes in window properties, the progress toward the energy target, and the impact of altering the building shell on the required capacity of the mechanical systems. The following figures show samples of the energy analysis charts presented during the workshops that summarize these results.

Figure 2. Sample Economic Analysis Workshop Results

Economic Analysis	
Incremental Costs ($)	
Equip. & Labor	$47,000
Annual O&M	$0 /year
Cooling System**	$500 /ton
Heating System**	$4 /kBtuh
Fans & Pumps**	$0 /hp
Net Savings/Year	*$13,035*
Net Capital Cost	*$40,979*
Payback @ 7.0%	***3.5 years***
LCC: $24.37 million, (-$115,546)	

Figure 3. Sample Peak Load Workshop Results

Maximum HVAC Contribution During Peak*			
HVAC END-USE	**Demand Base**	**Demand ECM**	**Peak Load Reduction**
Fossil Heat (kBtuh out)	10,222	9,728	493.3 (4.8%)
Steam Heat (kBtuh out)	0	0	0.0 (0.0%)
Electric Heat (kBtuh out)	0	0	0.0 (0.0%)
Cooling (tons output)	402.2	394.1	8.1 (2.0%)
Fans & Pumps (hp)	368	360	8.4 (2.3%)
*Coincident with building; thus, values do not necessarily reflect absolute maximums.			
Reference Savings - GJ:	7,609 (16.2%)		**Incent:** $0
CO2 Savings in kg -	**Base:** 102,035		**Ref.:** 299,103

It is important to note that life-cycle economic efficiency, not energy efficiency, is typically the focus of the program. However, this can vary from project to project, depending on the owner's interests and objectives. *The primary component that Design Assistance brings to the workshop is the ability to show the impact of various measures on annual operating costs.* Energy efficiency is allowed to seek its appropriate level within the context of the project's life-cycle costs.

At the end of the session, all measures deemed acceptable are "rolled up" into a single package. This is necessary to determine the overall progress towards the energy target, and is also necessary because some measures will affect the savings from other measures (e.g., the savings from improved windows will be diminished when paired with a more efficient boiler).

RESULTS

After applying this integrated design approach to many buildings, we have been able evaluate our results both qualitatively and quantitatively. We base the qualitative assessments on the process: What components lead to an interactive, "successful" project? The quantitative results summarize general trends we have found from performing energy simulations: Which technologies lead to cost effective, energy-efficient buildings? Which measures don't make sense economically?

Process Lessons Learned

Each workshop and design team has its own ambiance and team dynamics. In our experience, however, the most positive and successful workshops occur when the participants park their egos at the door, and open their minds to unexpected outcomes.

We have had the opportunity to attend several conferences where the theme of integrated building design is presented as a kind of Holy Grail: an item worthy of searching and striving for, but is ultimately complicated, convoluted, and costly. On the contrary, our experience has shown that integrated design does not require excessive use of the design team's time, yet does allow the full quantification of the interactions among the building shell, mechanical, and electrical systems.

The earlier the process begins, the better the outcome. The most successful projects begin once the building's basic form has been decided, but prior to any detailed mechanical design, or even mechanical system selection. Beginning a project at this stage not only allows for energy-efficient measures to be integrated most cost effectively, but it also leads to team interaction throughout the entire design.

In summary, the Design Assistance integrated design process involves the following steps:

- The design team provides information about the building, typically in the form of floor plans, sections, and elevations from the architect, and design development documents from the mechanical and electrical consultants.
- An energy analyst then constructs building energy models of the Proposed and Reference buildings, contacting the design team for clarification as necessary. Coordination with the mechanical consultants at this stage is a priority. The mechanical consultants dictate which mechanical systems are modelled, and they must have buy-in to the simulation results. For instance, it would not make sense to model a mechanical system the mechanical consultant was neither willing nor able to design. The modeller must also discuss CBIP-compliance issues that may run contrary to various mechanical engineering "rules of thumb," such as the delivery rate of supply air.
- Approximately 3 weeks after collecting the information from the design team, the Energy Performance Workshop is held. The workshop report is typically made available within 2 weeks of the completion of the workshop. There is no need for the design team to wait for the workshop report to proceed with their design if the project is time constrained, as the report is only a summary of the workshop findings, and typically contains no new information.
- If further analysis is required after the workshop, additional modelling can be completed. It has been suggested that an iterative workshop approach would be more effective, but that has yet to be determined. To date, providing as-needed modelling feedback has been satisfactory.
- After the completion of tender drawings, the models are finalized and the results are sent to CBIP for processing.

It should be noted that the above process is different than the standard end-of-process CBIP evaluation via the EE4 Comply compliance software. In this regard, Design Assistance has special dispensation from CBIP (based on our historical involvement in the CBIP program and advanced level of modelling expertise). That is, we develop the required models using "raw" DOE2 files and make the incentive application without completing an EE4 Comply file. We use EE4 Comply to assist with inputting the physical description of the building, but not to test compliance. With our approach, the design team receives substantial feedback prior to starting working drawings. Thus, they are able to make design changes as necessary to ensure the building meets CBIP energy targets. This is not the case if the team waits until the creation of tender documents to confirm compliance, which is typically the time the EE4 Comply file would be created.

There seems to be a balance between inviting as many players as possible to the integrated design workshop and maintaining a flow to the session. While we recognize that the process can be more "informed" with more participants, we have also experienced sessions that drag on interminably while non-technical people struggle with basic design concepts, and non-prime players (e.g., structural consultants) are forced to spend hours listening to issues which have no bearing on their design. In essence, we like to invite a good cross section of involved people, while keeping the meeting small and focused.

One of the key issues to a successful workshop is the energy target provided by the CBIP Reference building model. This aspect adds a singularly compelling dynamic to the workshop by boiling all the analysis down to a single indicator of success or failure. A workshop populated with highly motivated professionals all focusing on the same result is capable of producing excellent and sometimes surprising results. Upon careful reflection, it should come as no surprise that this is the case. Standard practice for most of the buildings we have modelled has been in the range of 10%–15% better than the CBIP Reference building. However, given the benefit of a target, and a means of measuring the results of their various design decisions against the target, very few teams have failed to comfortably exceed the required 25% target.

Having said all that, the success of achieving energy performance targets increases with the active participation of the entire design team since the forum allows everyone to beneficially contribute to the process (as further supported by Case and Wingerden, 1998; Montross and Fraser, 1998; Hayter et al., 1998). In particular, the interest and motivation of the mechanical consultant and the building owner are primary indicators for a successful project

Technical Lessons Learned

Although we now have three years and a couple of dozen projects under our collective belt, we never know the outcome of a project until we completely finish the analysis. In other words, every building is different with its own set of unique dynamics on energy performance. Having said that, there are several broadly applicable technical lessons we have learned:

- The two most important issues that affect a building's energy use have to do with ventilation air. First, we have repeatedly found that the amount of air should be controlled carefully by scheduling the volume appropriately for the number of building occupants and/or by using other forms of demand ventilation (e.g., CO_2 sensors). Second, heat should be recovered from exhaust air with the most effective means possible that meets the client's cost-effective criteria. This issue typically has the greatest impact on energy use (with the possible exception of office buildings, depending on the HVAC system type).
- We rarely have found daylighting and lighting occupancy controls to be cost-effective. These measures are only cost-effective when a single point can control a large number of luminaires, or when the sensors can be used in conjunction with a demand ventilation strategy. The most cost-effective lighting control is multiple switching coupled with occupant education.
- Building massing options and orientation are *not* major energy items in most commercial buildings. While important issues may arise in regard to massing and orientation, it is rarely worthwhile investing in the time to quantify the associated energy impact. We have routinely rotated buildings to determine the impact of orientation, and found resulting changes in annual operating cost vary by only 2% at most. This is not to suggest that anything goes for the building shell, but rather that detailed energy simulation is not necessarily the most cost-effective means of assessing the effects. We would suggest not explicitly quantifying the relative impacts, but instead, have good practice for optimizing solar exposure combined with the owner's program and site issues be the driving forces in addressing massing issues.
- Mechanical system selection is a critical decision that will make or break any chance of success for a project. Preferred mechanical systems include heat pumps (water loop and ground source), fan coils, VAV, and unit ventilators (which currently have a reputation for being a cheap system, but show good potential for both demand ventilation and even heat recovery). Ground-source heat pumps save a significant amount of energy, but have not yet been shown to be cost-effective in the B.C. market, except in projects where the loop installation costs can be ameliorated.
- Condensing boilers were rarely cost-effective, even without considering additional maintenance issues. However, with the dramatic gas price increases recently, this has been changing in some cases. Typically, the most cost-effective boiler option is a medium efficient (85%), fully modulating boiler.
- The issue of reheat can be a significant factor, based on the type of mechanical system and zoning. (Reheat occurs when air from a central system is cooled to meet the cooling requirements of the warmest zones on the system, but then requires terminal heating for other zones which otherwise would become too cold.) However, in other cases, the issue is overstated. This all depends on how the HVAC systems and associated zones are defined.

- Glazing results are very building dependent. No strong trend has emerged, although we have not found a project where the most energy efficient of glazing systems (e.g., triple low-e glazing) is cost-effective.
- Roofs are often over insulated from a life cycle costing perspective. R20 seems to be in the ballpark for a cost-effective value, with the recent increases in gas prices included. Likewise, cost-effective wall insulation values are in the range of R12. We have often shown that values in excess of these are not cost-effective. The design team may prefer to see the capital re-allocated to more important mechanical items, depending on the budget constraints.

It is important to note that the trends we have observed are based on studies of building designs primarily in the southwestern B.C. area, where temperatures are relatively mild and electricity prices are among the lowest in North America. However, we have also found similar trends in other jurisdictions. The life-cycle cost-effectiveness of more aggressive energy-efficient measures may increase in colder climates and/or when higher utility costs are applied. Therefore, it is important to examine measures on a building-by-building basis.

One important issue that bears commenting on is the noticeable difference in technologies implemented in buildings that have been heavily marketed as "green," and the results of our own Energy Performance Workshops. We are having a hard time resolving the difference between our results, which have been repeatedly verified with computer simulations, and various projects that are being advertised as green and energy efficient which incorporate technologies that we believe are neither cost-effective nor save significant amounts of energy. The following technologies are those that seem to have the widest positive "green" press coverage, but provide the least cost-effective energy savings:

- Natural ventilation: We have repeatedly shown that if the opportunity cost of providing for natural ventilation means that heat recovery can't be used, this technology is a losing proposition from the energy perspective. Fan energy is a very small piece of the energy pie compared to the amount of energy required to heat outdoor air. Also, there often is a significant cross effect issue with space heating. Any fan energy (which eventually ends up as heat in the airstream) that is avoided would need to be replaced by the conventional heating source during the heating season. The image of a building that saves large amounts of energy by simply drawing in its own air as required without mechanical effort belies all analysis we've done to date. This is not to say that natural ventilation is not a good opportunity, but that it needs to be fairly assessed on its own merits and in relationship to other measures.
- Daylighting: While we are fully supportive of any effort to introduce natural light into the building from a psychological and human productivity standpoint, it has little bearing on overall energy use. Thus, it rarely is cost effective to install the associated controls required to harvest it. This becomes even more exacerbated in cases where cooling is negligible (e.g., most schools in B.C.) due to the reduction of heat gains from lights.
- Super Insulation: This may work in the residential sector, but analysis has repeatedly shown that over insulating a building is not cost-effective.

Program Results to Date

The Design Assistance program originated in mid-1998. Not including the initial pilot projects, we have conducted analysis on 27 buildings, totaling approximately 350,000 m^2. There have been private and public sector projects, including offices, schools, lab buildings, airport facilities, long term care facilities, a maintenance facility, and a fire hall. Of the 27 projects, 20 have been through the complete program, including the Energy Performance Workshop. For the remaining seven projects, we have conducted some analysis, including CBIP facilitation, but no workshop. Of the 27 projects, 25 projects were interested in applying for a CBIP incentive (two projects were owned by the Federal government, which cannot apply for CBIP incentives). Of the 20 projects that have been through the Design Assistance program, all but two have been shown to qualify for a CBIP incentive. The summary statistics for those 20 projects is below.

Savings vs. Reference		Savings vs. Baseline	
Dollars	GJ	Dollars	GJ
$695,603	103,561	$644,549	99,200

Note that the above table contains summaries of historical information, and many projects were completed prior to the recent increase in gas prices, which would increase the dollar savings item considerably.

We have been pleasantly surprised since the middle of this summer by the emergence of a trend that has seen projects surface from workshops with the best possible outcome of reduced energy and capital cost compared to the Baseline, while attaining a maximum CBIP incentive. In other words, energy was saved while construction costs was *reduced*. In all, four projects have achieved this outcome.

The first thought most people have when talking about energy efficiency is: "How much will it cost?" That is one reason why we position Design Assistance as maximizing economic efficiency, not just energy efficiency. Typically, we have been happy to mine all of our projects for any energy efficiency measure which will come in under a (typically) 5-10 year payback, depending on the payback tolerance of the client. However, this new trend shows that a careful review of various measures can actually reduce energy consumption and the capital cost of the building by re-allocating resources to the most cost-effective energy conservation measures. This is certainly not a general trend that applies in all cases, but nevertheless is gratifying to witness on occasion.

The following table is a companion to the previous table, showing the average additional capital and maintenance costs. It also shows the associated energy savings and resulting overall payback of the 20 projects. The payback is assessed by comparing the final bundle of energy efficiency measures from the workshop to the baseline model, using a discount rate (typically 7%) over a 20-year analysis period.

Economic Analysis			
Incremental Capital	Annual Savings		Payback in Years*
	O&M	Energy	
$84,038	$762	$51,145	2.8

*Includes discount rate.

CONCLUSION

Our experience has shown that the process produces more energy efficient buildings with an attractive payback. The Energy Performance Workshop approach to integrated design is able to take any team and project through its design session and focus the team on achieving significant savings. This has come at a relatively small incremental design cost and with the likelihood of achieving those savings with a reasonable payback, if not actually reducing the cost of the building.

We would like to further consider two other aspects of the Design Assistance approach. Firstly, we do not replace anyone on the design team. As we often state in our workshops, "The design team is the artist, we only want to be a better paint brush." We do not tell the design team what to do, nor are we the "energy police." Secondly, while emphasizing that we were not necessarily interested in creating a budget-oriented service, the approach responded to market pressures (alleviated to a certain degree by CBIP incentives) in arriving at a scope of work which would improve the commercial building design process, but at a price that was acceptable in the market. This second point is key, as the industry needs to come up with a sustainable alternative design process for a post-CBIP world. That process cannot be onerous and expensive, or it will not stand the test of time and contribute to market transformation.

It is also important to view our findings in the proper context. All buildings are different, and measures that were or were not cost-effective in our studies may have different outcomes in other regions with different climates and/or utility rates. Therefore, instead of emphasizing the results of the program, we would like to emphasize that the process of using modelling in an integrated design setting allows the design team to bring forth ideas and discuss the potential, often leading to innovative, energy-efficient, and cost effective solutions.

REFERENCES

Case, M.E. and J. Wingerden (1998), Incentive Program for Energy Efficient Design of State Buildings, *ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, 4.37–4.48.

Hayter, S.J., P.A. Torcellini, R. Judkoff, and M.M. Jenior (1998), Creating Low-Energy Commercial Buildings through Effective Design and Evaluation, *ACEEE 1998 Summer Study on Energy Efficiency in Buildings,* American Council for an Energy-Efficient Economy, 3.181–3.192.

Hepting, C. (1996), Hourly End-Use Energy Analysis as a Value-Added Customer Service, *ACEEE 1996 Summer Study on Energy Efficiency in Buildings, Commercial Buildings: Program Design, Implementation, and Marketplace Issues,* American Council for an Energy Efficiency Economy.

Hepting, C. and D. Ehret (1998), The "BEST" New Commercial Design Program, *Green Building Challenge '98: An International Conference on the Performance Assessment of Buildings, Volume 2,* Natural Resources Canada.

Hepting, C., D. Ehret, and M. Mottillo (2000), Web-Based Building Performance Assessment: The CBIP Screening Tool, *Building Energy Simulation User News*, 21(6), Lawrence Berkley National Laboratory. A variation of this paper was also presented as a poster paper at the Sustainable Buildings 2000 conference in Maastricht, The Netherlands, Oct. 2000.

Montross, C. and M. Fraser (1998), Building Design for a Sustainable Future. *ACEEE 1998 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, 4.285–4.295.

ACKNOWLEDGEMENTS

This paper would not be complete without recognizing the contribution of Natural Resources Canada's Commercial Building Incentive Program, which has indirectly provided the financial engine for our program.