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USING BUILDING SIMULATION TO SUPPORT AN ENERGY-EFFICIENT INCENTIVE PROGRAMME

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ABSTRACT

This paper provides an overview of how building simulation is used to support a Canadian Government energy-efficient incentive programme. It describes the two software tools (detailed simulation software and a simplified web-based method) that were developed to support the programme. The classroom and computer-based initiatives used to train users are also described, this being key to support programmes of this nature.

INTRODUCTION

Natural Resources Canada (NRCan), a ministry of the Canadian Government, launched a financial incentive programme in 1998 to encourage the construction of energy efficient commercial buildings. Financial incentives are paid to the building owner at the completion of the design phase. The magnitude of the incentive is based upon the energy efficiency calculated using simulation. This paper describes how simulation is used to support the incentive programme. It touches upon software tools and user training. Details of the incentive programme are not treated here due to space limitations. Rather, the interested reader is referred to the following URL which provides full details on procedures, financial incentive levels, and technical requirements: http://cbip.nrcan.gc.ca/cbip.htm.

The paper commences with a overview of the methodology used to quantify the building's energy efficiency. It then describes two software tools that were developed to assess building energy efficiency to support the programme. The first is a web-based tool that provides a rapid screening of the design to the technical criteria. This is used at preliminary design stage and allows architects and engineers to estimate the impact of design alternatives. The second software tool is based upon a detailed simulation approach which quantifies the efficiency of the completed design. The design of the user interface, error checking routines, automatic report generation, and the implementation of the programme modelling methodology are discussed.

Significant effort was placed on training architects and engineers to use the simulation tools. The paper discusses the content of training courses and manuals and discusses how the tools are supported. Particular emphasis is placed on the design and development of a multi-media training course that is distributed on CD-ROM.

Finally, conclusions on the effectiveness of these training initiatives and software tools are drawn and recommendations made on the use of simulation to support energy efficient incentive programmes.

METHODOLOGY FOR QUANTIFYING BUILDING ENERGY PERFORMANCE

The financial-incentive programme is based upon a reference building approach, wherein the performance of the design is contrasted against a reference building constructed with representative envelope, lighting, and HVAC systems. A whole-building performance philosophy is used to give designers maximum flexibility. As such, the designer can opt for any solution (certain limitations do apply) in terms of HVAC, lighting, and envelope design as long as the overall energy consumption of the building is no more than 75% of the level it would consume had it been built according to the Canadian Model National Energy Code (NRC 1997). Conceptually, this reference building approach is very similar to that employed in other energy efficiency standards, codes, and incentive programmes (e.g. CEC 1999; ASHRAE 1999).

As an example of the whole-building performance approach, a designer may choose to focus on finding efficiencies in the areas of lighting and HVAC while using conventional envelope construction. Similarly, a conventional HVAC system may be sufficient if high-performance windows and high levels of roof and wall insulation are used in conjunction with reduced lighting power.

In the vernacular of the incentive programme, the solution chosen by the design team is referred to as the *proposed design*. Building simulation is used to quantify the energy performance of this design. The designer inputs details on the envelope, lighting, and HVAC systems to the simulation program. Certain assumptions regarding operating conditions, such as heat gains from occupants and lighting schedules must be followed. Following this, a simulation is conducted with standard weather data to estimate the building's annual consumption of electricity, natural gas, oil, and other fuels.

A second simulation is then conducted for comparison purposes. A model of a *reference building*, having the same size, shape, occupancy, temperature set-points, equipment, operating schedules, and orientation as the proposed design is constructed. The envelope characteristics are established based on geographical location and the type of fuel used to heat the building. A lighting system considered to be good practice for the intended occupancy is selected.

Finally, the HVAC system type and component efficiencies are established, once again based upon good practice. For example, if the proposed design is conditioned with a water-loop heat-pump system that employs a gas-fired boiler and cooling tower to maintain the loop temperatures, then the reference building will have a variable-air-volume system with a gas-fired boiler and an electric chiller serviced by a cooling tower. Boiler and chiller efficiencies, pump and fan capacities and efficiencies, and fan-control mechanisms are all functions of size and established using a complex set of hierarchical rules.

A simulation using the same standard weather data is then performed with the reference building model and the results contrasted against the first simulation. If the predicted energy consumption of the proposed design is no more than 75% than that of the reference building, then the design is eligible for a financial incentive. This methodology is illustrated in Figure 1.

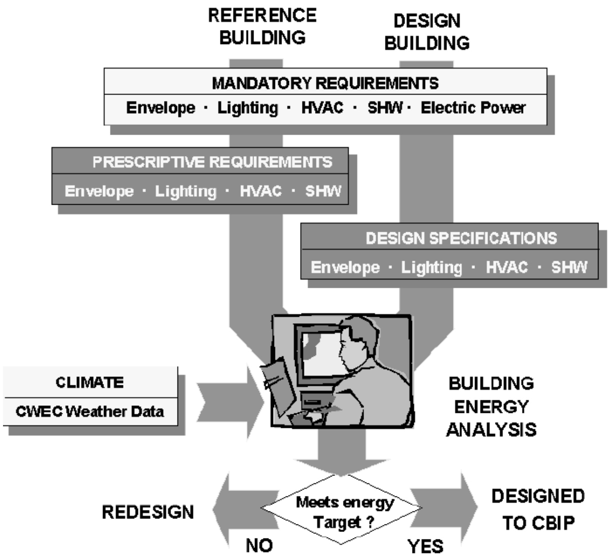

Figure 1: Reference building procedure

The process described above would be a practical impossibility within the context of tight design schedules and budgets without customized simulation software. To this end, two pieces of software were developed to support the incentive programme: a web-based screening tool and EE4 CBIP. These are described in the following two sections.

WEB-BASED SCREENING TOOL

The CBIP screening tool is a web-based application that assists proponents in determining whether their design is close to complying with the programme requirements. While not definitive, it can be used to rapidly assess whether a design is likely to comply. It is also a useful design tool as it allows architects and engineers to quickly estimate the impact of design alternatives at the conceptual design stage when insufficient data are available for performing detailed simulations.

The screening tool enables these types of analyses by defaulting a significant number of parameters that affect energy usage. For example, to assess the impact of switching to a high efficiency condensing boiler, the user need only specify the full-load efficiency and the fuel type. All other data characterizing the boiler and its ancillary devices are defaulted: part-load performance curve, circulating water pump power draw and head, etc.

In total, fewer than 50 data inputs are required to completely describe a building. A combination of pick lists, default values, and numerical inputs are used to speed data entry (Figure 2 illustrates a typical input screen). Data are required to describe the following:

- geographical location;
- building type and floor area;
- areas and U-values of envelope components;
- HVAC system type;
- heating and cooling efficiencies;
- fresh air ventilation rates and control;
- lighting power density and type of daylighting and occupancy sensors;
- fuel and electrical costs.

Mechanical System	Reference Building	Your Design
Heating efficiency:	80.00%	94.00 %
Minimum outside air:	0.40	0.40 l/s/m²
Percent of floor area cooled:	100.00%	100.0 %
Cooling efficiency:	5.20	5.20 COP
Outdoor air economizer?	Yes	☐ Yes
Efficiency of exhaust air heat recovery:	0.00%	65.00 %
Service water heating fuel type:	Fossil	Fossil
Service water heating efficiency:	80.00%	94.00 %

Figure 2: Screening tool HVAC input screen

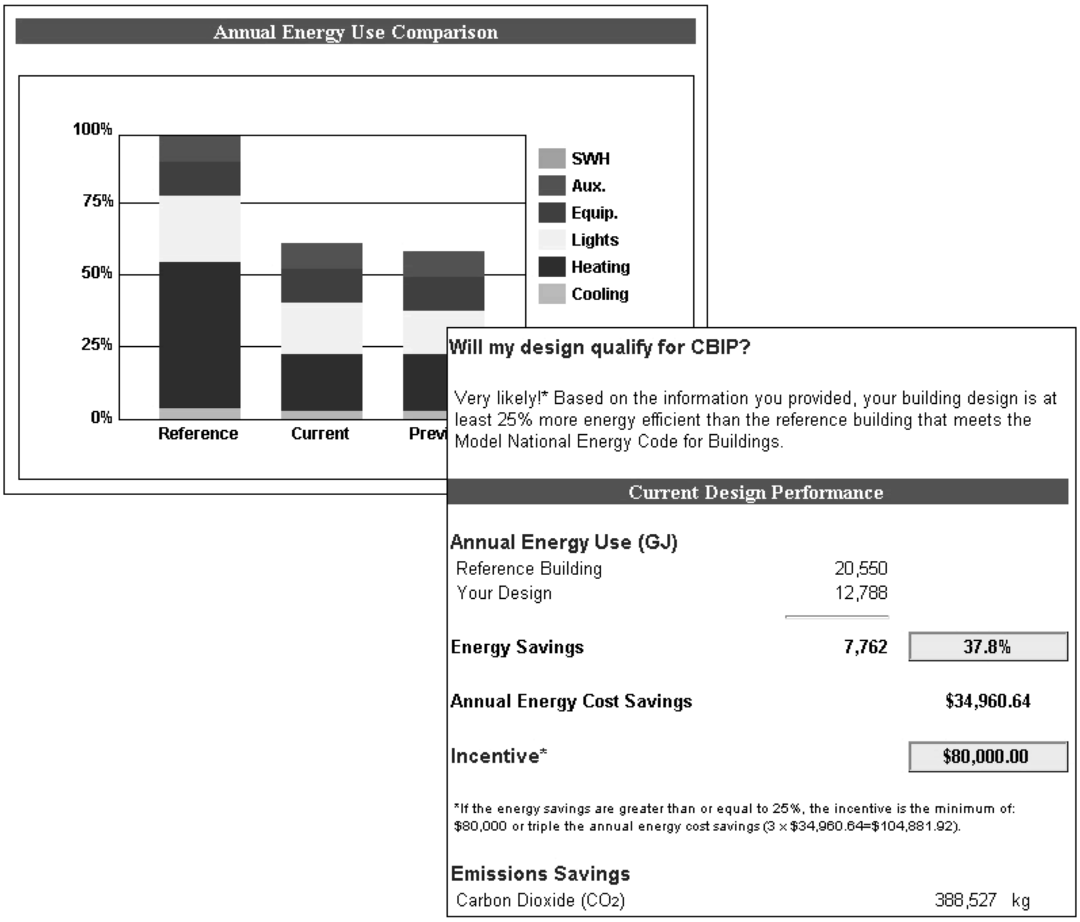

Figure 3: Screening tool results output

The screening tool provides results on operational energy consumption and cost and greenhouse gas emissions. The building's projected energy end uses (heating, cooling, lighting, etc.) are contrasted graphically against those for the reference building (refer to earlier discussion) and for previous design iterations. The screening tool also provides a clear indication of whether the design will likely qualify for a CBIP programme incentive and estimates the financial incentive. Typical outputs are illustrated in Figure 3.

The energy calculations are based upon a regression method. 85 000 parametric simulations were performed with the DOE-2.1E building simulation program (Winkelmann et al 1994). For specific combinations of building type, location, HVAC system type, and heating fuel, these data were regressed to correlate monthly energy end-use and demand to envelope U-values, equipment efficiencies, lighting power density, etc. These correlation equations are then used to estimate the building's energy performance by quantifying the impact of deviations in parameters (e.g. wall U-value) from a base case.

The screening tool enables a rapid assessment of a building's energy performance with minimal data input. However, this does come at a cost. Only the seven most common building types can be examined and a limited number of HVAC configurations can be considered for each. For example, office buildings with the following systems can be analyzed:

- electric or gas-fired variable-air-volume systems;
- fan-coil units, with or without electric perimeter reheat;
- gas-fired distributed heat pumps;
- ground-source heat pumps.

A more detailed simulation approach must be used for buildings that fall outside these constraints.

The interested reader is encouraged to examine and run the screening tool at the following URL: http://nrn3.nrcan.gc.ca/cbipscreen/.

EE4 SIMULATION PROGRAM

The *EE4 CBIP* software was developed to support the financial incentive programme. It performs a detailed energy simulation of the proposed design and reference building according to the procedure previously outlined. The software is composed of three principle components: a graphical user interface, a CBIP rules processor, and a simulation engine.

User interface

The user interface was designed for ease-of-use by practicing architects and engineers. It was developed in C++ as a Microsoft Windows 32-bit application. A tree structure is used to organize the data in a hierarchical manner (refer to Figure 4). The lowest level of the tree contains global data such as the geographic location, and fuel and electrical cost data. The next two levels contain data on the central HVAC system: the first pertains to the central plant (boilers, chillers, cooling towers, circulating pumps) while the second relates to secondary systems (fans, heating and cooing coils, economizers, etc.). Information on the building fabric and lighting are arranged in higher levels of the tree. This tree structure allows users to organize the extensive data required to simulate a complex building in a logical fashion that facilitates model creation and maintenance.

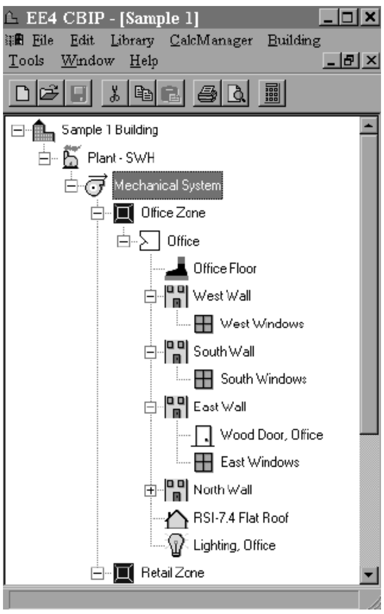

Figure 4: EE4 tree structure

Data are associated with each node of the building tree through dialogue and forms (some samples are shown in Figure 5). Data entry to the dialogues is assisted through libraries, which allow the user to re-use components (boilers, windows, wall assemblies, secondary HVAC systems, etc.) from one project to another. A search and replace facility is also provided to allow users to quickly modify a model, this allowing, for example, all occurrences of a window to be replaced with a higher performing unit.

An fully searchable on-line help facility (see Figure 6) documents each input, includes HVAC system

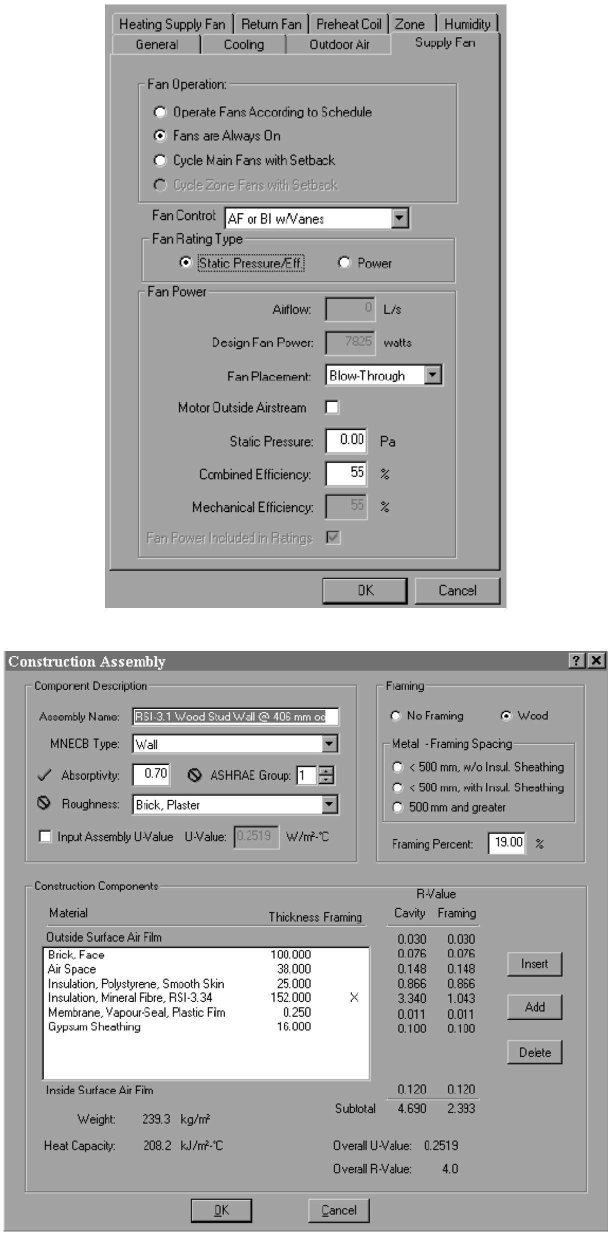

Figure 5: EE4 input dialogues

schematics, and offers context sensitive help.

CBIP rules processor

Once the user has completed the description of the building and commissioned a calculation, control is passed to the rules processor. It manages the application of all CBIP rules and prepares the proposed and reference models for the energy simulations. Two levels of diagnostic checking are first performed. The first level diagnostics ensure that all required inputs have been specified and that allowable ranges (e.g. for envelope U-values) have been respected.

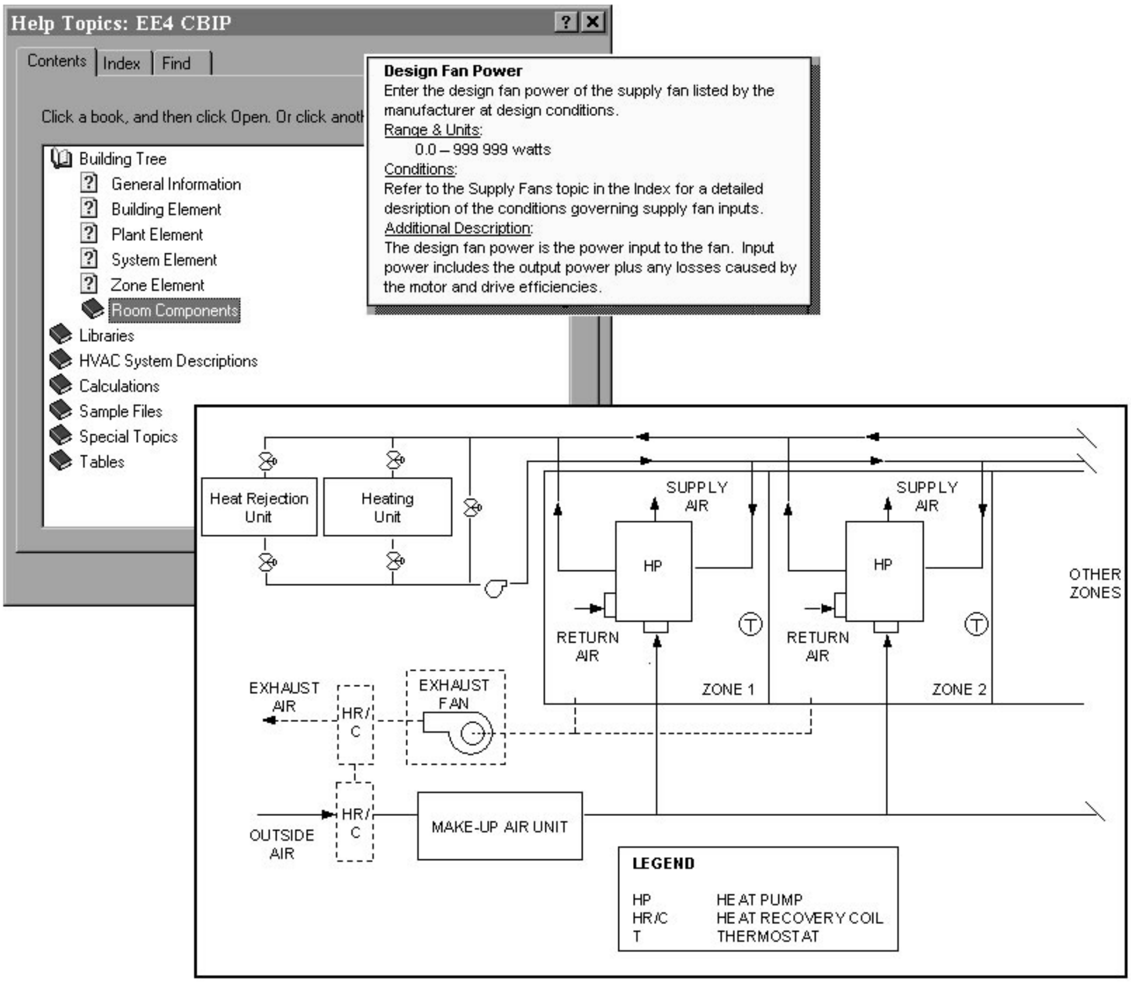

Figure 6: EE4 on-line help system

Following the successful completion of these diagnostic checks, the rules processor performs sizing calculations using industry accepted standard procedures (ASHRAE 1997) to ensure that heating, cooling, and ventilation equipment are adequately dimensioned to respond to peak heating and cooling demand. In most cases these diagnostic checks result in a series of warnings and errors.

The diagnostic wizard is used to bring this information to the user's attention and to provide guidance on adjusting the model or design to address the problems. For example, Figure 7 illustrates a warning message indicating that a secondary HVAC system has insufficient capacity to meet the peak cooling load imposed by the zones served by the system. Since the incentive programme allows buildings to be under-cooled (but not under-heated), this warning is provided for information only. Some guidance is given to the user on how the problem could be addressed.

Once all diagnostic errors have been resolved, the rules processor applies the incentive programme's rules to create simulation models of the proposed and reference buildings. The generation of the reference building is automated and requires no interaction from the user. A complete description of both buildings' fabric assemblies, lighting, and HVAC systems is assembled and input files for the simulation engine created. Extensive testing has been performed to ensure that the CBIP rules are accurately applied in preparing the simulation input files.

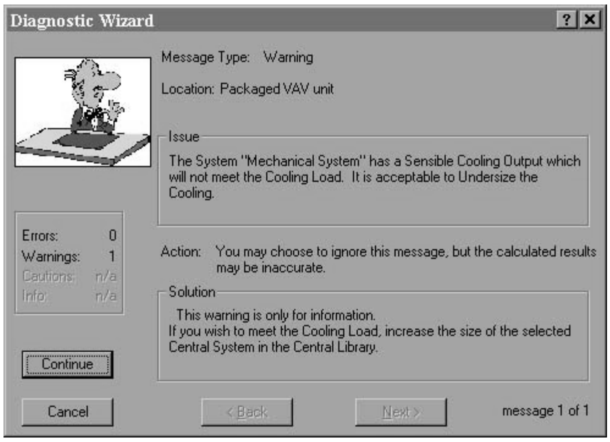

Figure 7: EE4 diagnostic wizard

Simulation engine

EE4 performs annual simulations of the proposed and reference buildings using the extensively validated DOE-2.1E simulation program (Winkelmann et al 1994). To prevent tampering with the simulation results, the user has no opportunity to interfere with this process. The rules processor creates the DOE-2.1E input file immediately prior to invoking the simulation. And immediately following completion of the simulation, the rules processor extracts the necessary results from the DOE-2.1E results file.

It should be noted that the EE4's functions that create the DOE-2.1E input files have been isolated from the incentive programme's rules set, this to facilitate switching to an alternate simulation engine in the future should a better alternative arise.

Determining compliance

A standard (simplified) sizing check using design day data was performed prior to performing the energy simulation, this to ensure that heating, cooling, and ventilation equipment is adequately sized to meet the anticipated loads. These calculations are confirmed by examining the results of the detailed simulation. Should the HVAC system be unable to maintain the set-point temperatures (within a reasonable threshold), a diagnostic error (in the case of heating) or warning (in the case of cooling) will be issued.

The simulation results from the proposed and reference buildings are then contrasted to determine whether the design meets the programme's energy target. Whether the building complies or not, a report echoing all input data and summarizing the simulation results is created. The report is created in HTML using a customized toolkit and displayed to the screen with an embedded web browser. This HTML reporting tool is a recent feature of EE4 that was developed to produce tamper-proof high-quality reports suitable for sign-off by the design professional (Figure 8 provides an example) as well as graphical output.

The EE4 software is distributed by the web and is enhanced on a regular basis. The interested reader is invited to download a fully functional copy of the software at the following URL: http://ee4.com.

TRAINING COURSES AND MANUALS

The development of compliance-checking software tools was not sufficient in itself to support the incentive programme. A key programme objective was to have the design teams perform their own simulation work. Consequently, as many Canadian architects and engineers do not currently use energy simulation tools (many use software to size HVAC systems but not to analyze energy consumption), a

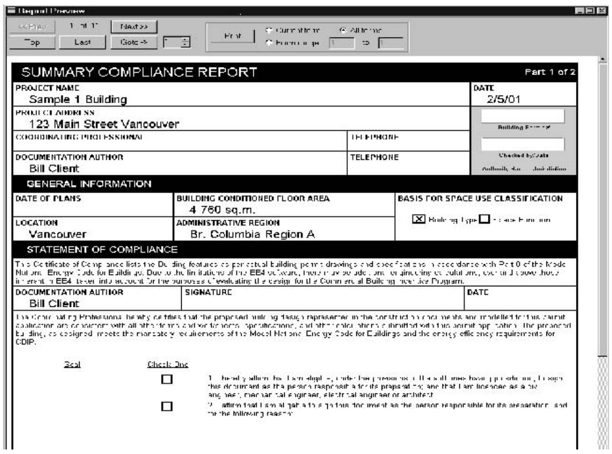

Figure 8: EE4 compliance report

substantial effort was placed upon training.

Two courses were developed to train voluntary participants from industry: an introductory course and a specialized modelling course. The introductory course describes the intent and scope of the incentive programme and provides an overview of the technical requirements for compliance, It also includes an overview of the principles of simulating buildings and a demonstration of the EE4 software. This one-day course provides sufficient information to building developers and owners for decision-making purposes and gives designers the introductory information required to commence using the EE4 software. This course has been delivered to 400 participants in 15 cities across Canada. It has proven to be critical in raising awareness of the programme.

The second course is specifically targeted at the technical staff tasked with performing the EE4 simulations. The objectives of the course are to enhance building simulation (and specifically EE4) skills and to encourage standardized procedures that can streamline compliance-checking and verification. A combination of lectures, case studies, and hands-on exercises are used throughout the one-day course. This course has been delivered to 225 participants in 15 locations across Canada.

A complementary building modelling guide has also been created. This document acts as a repository for modelling rules, guidelines, and lessons learned throughout the programme. It provides information on zoning principles, modelling complex HVAC systems, and specifying complex fuel and electrical utility rate structures. The interested reader is invited to download a copy of this guide at the following URL: http://www.buildings-group.net/ee4/cbip_e.html.

MULTI-MEDIA TRAINING

A computer based training course (CBT) was developed to complement the training workshops and manuals discussed in the previous section. This CBT serves two purposes: it replaces the workshop for users who are unable to attend a training course due to geographical constraints; and, as it provides in-depth information on specific topics, it acts as a source of reference material for all users.

The CBT's total run time is about four hours, although its self-navigation features allow users infinite choice in the order and extent of learning (Figure 9 illustrates the course map). The following topics are covered:

- the incentive programme rules and technical requirements;
- some basic principles of building modelling;
- the use of the EE4 simulation software.

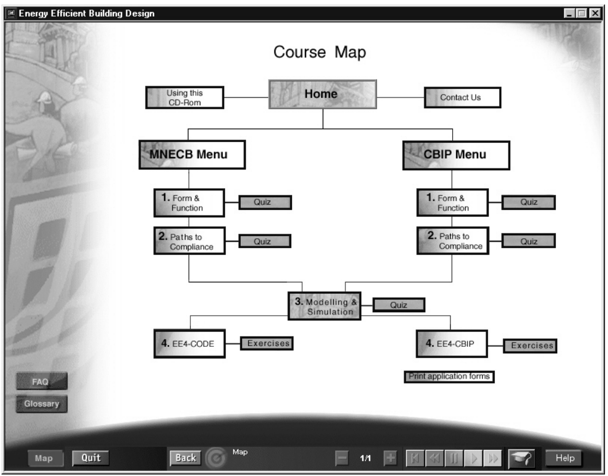

Figure 9: CBT course map

The CBT was developed by a team which included a subject matter expert, an instructional designer, a graphics designer, a multimedia designer, and software testers. The subject matter expert (a member of the EE4 software development team) provided the technical content while the instructional designer organized the material to maximize its instructional value. The instructional designer determined the combination of narration, static graphics, text, and software simulations to best communicate the material and prepared narration scripts. The design and scripts were validated by the subject matter expert prior to the production work. The multimedia designer and graphics designer then implemented these concepts into electronic format (e.g. WAV files for sound, JPEG and GIF files for static graphics). Finally, the electronic components were assembled into a beta version of the CBT using a multi-media production package, and a team of testers examined the course in detail before the final production.

One of the interesting features of the CBT is the use of quizzes. Each of the seven learning modules ends with a short quiz to allow users to test their knowledge of the information covered in the module (an example is provided in Figure 10). When users have existing knowledge of a module's content, they can use the quiz to confirm their knowledge before deciding whether to follow the path through the module. In this way, users can take advantage of the CBT's navigation features to focus their studies on the specific subjects where their knowledge requires enhancement.

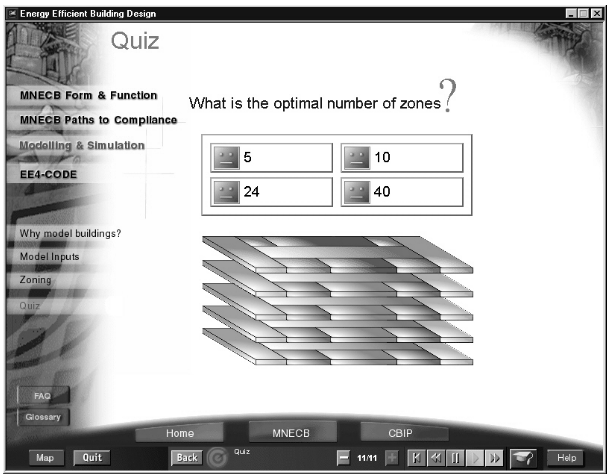

Figure 10: Use of quizzes in CBT

Another interesting feature is used to demonstrate the operation of the EE4 software to new users. The sequencing of multiple screen captures in conjunction with narration easily communicates basic concepts regarding software operation. With this, the cursor is made to navigate through a series of menu selections and dialogue boxes while narration is used to explain specific input requirements (refer to Figure 11). User interaction is required at certain points in this process to prevent concentration drift.

Figure 11: Demonstrating software operation in CBT

Once the basic concepts of EE4's operation have been described, the CBT provides users with assistance to apply their new skills on a worked example. With the CBT and EE4 running concurrently, the user is prompted to open an EE4 file included with the CBT. The CBT provides step-by-step instructions and hints on completing the data description of the building (see Figure 12).

These techniques assist new users to learn the operation of the EE4 software with minimal time investment, and as such allow them to focus their efforts on the act of building simulation, rather than tool operation.

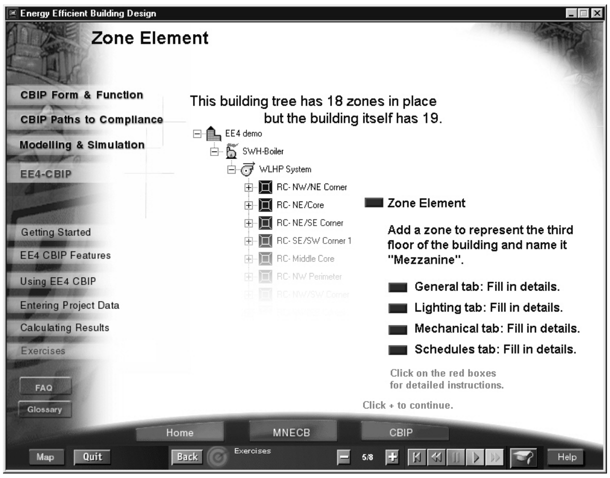

Figure 12: Guiding first use of EE4 in CBT

CONCLUSIONS AND RECOMMENDATIONS

This paper has provided an overview of how building simulation is used to support a Canadian Government energy-efficient incentive programme. Two software tools were developed, one for performing detailed simulations and the other for providing a rapid screening against the programme's technical criteria.

The latter tool was not originally conceived in the programme design, but its need became apparent rather quickly. Many developers and designers interested in the programme required a preliminary indication of whether the energy performance of their conceptual design was close to meeting the programme's target. A means for rapidly assessing the energy impact of major design decisions (e.g. type of HVAC system, heating fuel) was also required at the conceptual design stage, a time when detailed simulations are difficult to perform due to incomplete data.

A regression method was selected for the screening tool. Although this approach enables a rapid assessment, it limits the types and complexity of buildings that can be modelled. Consequently, it is recommended that alternate calculation approaches be examined for similar applications in the future. For example, a simplified user interfaces with intelligent data defaulting could enable a screening tool to be based upon a detailed simulation engine.

The detailed simulation software EE4 has, in general, been well received by the design community. EE4's interface was designed for ease-of-use by practicing architects and engineers. However, it was found that striking a balance between the needs of novice users and those of experience simulators, while ensuring that the programme's technical requirements were respected, was a challenge.

The EE4 software applies the programme's technical requirements, automatically creates the reference building, and generates a compliance report. These steps are critical from the perspective of an agency that is providing financial incentives for energy efficient designs (the same could be said for an agency charged with verifying that building and energy codes are being respected). The management of a programme such as this would not be practically possible without the inclusion of these features in software.

Considerable effort has been invested in training and supporting users. This is a key element that should not be overlooked in programme design. The availability of comprehensive on-line help and access to training (either classroom or computer-based) is critical, both in maximizing programme adoption and in minimizing one-on-one support costs.

ACKNOWLEDGEMENTS

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