DETERMINATION OF BUILDING ENVELOPE REQUIREMENTS FOR THE (CANADIAN) NATIONAL ENERGY CODE FOR BUILDINGS

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ABSTRACT

Canada will publish a new National Energy Code for Buildings (NECB) in 1995. The NECB will serve as a model for adoption by the provincial and territorial governments. It was developed at the request of the provinces and territories of Canada. They, along with the Canadian electrical utilities, provided financial support and actively participated in the development of this code. Although the NECB is derived in large part from ASHRAE/IES Standard 90.1 *and California Title 24, it is unique in several respects. Significant characteristics of the new code include the following.*

- *Economic Justification—Life-cycle cost analysis (LCC) is used to determine thermal requirements for building envelope components.*
- *Regional Sensitivity—At the request of the provinces and territories, these requirements are based on LCC analysis, which takes into account specific cost and economic assumptions for each region of the country.*
- *Fuel Sensitivity—The requirements depend on the heating energy source. For example, requirements for electrically heated buildings generally are more stringent than those for gas-heated buildings in the same location.*
- *Consultative Process—The requirements were determined in consultation with the provinces and territories.*

This paper describes the development process for the new energy code. A key element of this process is the LCC procedure employed to determine the building envelope requirements. This procedure involved development of a simple regression model to predict heating and cooling energy; development of a computerized analysis procedure to permit rapid LCC analysis; identification of representative wall, roof, and window constructions along with the thermal performance characteristics and construction cost for each; consultation with the provinces and territories to determine appropriate energy costs and economic assumptions to use in the LCC analysis for each region; and an established process for developing national model (building) codes that achieves consensus through a balanced committee structure and extensive public review.

INTRODUCTION

The (Canadian) National Energy Code for Buildings (NECB) will prescribe requirements for, among other things, the thermal characteristics of building envelope components (NRCC 1995). The NECB also features alternate compliance paths, but because these are based on the concept of "equivalent to prescriptive," it is the prescriptive requirements that establish the fundamental impact of the code on construction practice. This paper describes how these prescriptive values were determined.

The NECB was developed using a well-established consensus process that is used for all of Canada's national model codes, including the National Building Code of Canada (NRCC 1992). A committee of volunteers, drawn from all segments of the industry and representing all geographic regions of the country (the standing committee), is responsible for the technical content of the code. The development of the energy code was a cooperative effort involving the federal government, the provincial and territorial governments, and electric utilities represented by the Canadian Electrical Association. These stakeholders established a principle at the very beginning that the requirements should be economically justified, and further that this justification should take into account regional differences in construction costs, energy costs, and economic assumptions.

Sensitivity to regional conditions was an important consideration. A previous attempt to produce a national energy code (NRCC 1983) that was based on national average energy costs and construction costs met with

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poor acceptance by the provinces. One explanation for this was that most provinces felt the requirements were not right for them. Those with cheap energy felt the envelope requirements were too high, while those with high energy costs felt they were too low. Heating energy costs in Canada can range from \$2.91/GJ for cheap gas to more than \$38/GJ for expensive electricity, so it is not reasonable to expect the same insulation level to be optimum for all. Consequently, the envelope requirements for each region were based on life-cycle cost analysis (LCC) using assumptions appropriate for that region. For each region, the analysis produced envelope requirements that were fuel sensitive, that is, the requirements vary depending on the energy source used for heating. For example, in most regions an electrically heated building requires more insulation than one heated with natural gas.

APPROACH

The authors recognized that to customize the code requirements for each region of the country we would need to do a large number of LCC analyses. Therefore, we proceeded as follows. First, we developed a procedure that could be readily automated, and implemented it in computer software so that analyses could easily be repeated for different regions and different sets of proposed assumptions. Next, we applied this procedure by consulting with each province to obtain appropriate input assumptions, performed the LCC analysis, and presented the results to the province. This, in most cases, became an iterative process in which various assumptions were tested to determine what effect they would have on the envelope requirements. After this consultation the results were presented to the standing committee, which has the ultimate responsibility for the content of the code. The result was a set of requirements that had been examined by both the standing committee and by local/provincial representatives. Finally, these requirements were submitted to the process of general public review.

LIFE-CYCLE COST ANALYSIS

For the purpose of developing rational requirements for thermal characteristics of the building envelope, the life-cycle cost procedure was specified to account for the sum of the construction cost plus the present value of the energy costs over the time period assumed for the analysis:

$$\mathrm{LCC} = \mathrm{CC} + \mathrm{PVEC} \tag{1}$$

where CC is the construction cost and PVEC is the present value of energy costs.

Because we are only interested in the effect of changes in the building envelope on energy, we can deal with only the incremental costs for both construction and energy. There is no need for absolute costs; they can be incremental costs from an arbitrary reference point. Also, other costs and benefits, such as repair and maintenance, capital depreciation, and residual value at the end of the evaluation period, were assumed to be unaffected by the level of thermal performance of envelope components and thus represent no change to the incremental LCC being evaluated.

The present value of energy costs can be thought of as the sum of money, which, if deposited in a bank or invested in an annuity and withdrawn to pay for annual energy costs, would just be consumed (both principal and interest) at the end of the period. The present value of energy costs is the present value of annual heating costs plus the present value of cooling costs over the period of analysis:

$$\mathrm{PVEC} = \mathrm{PWF}_h \cdot R_h \cdot L_h / Eff_h + \mathrm{PWF}_c \cdot R_c \cdot L_c / \mathrm{COP}_c \tag{2}$$

where

PWF_h = present worth factor for the heating energy (fuel or electricity),
R_h = price of the heating energy (\$/MJ),
L_h = annual heating system load (MJ),
Eff_h = seasonal efficiency of the heating system,
PWF_c = present worth factor for the cooling energy (assumed to be electricity),
R_c = price of electricity (\$/MJ),
L_c = annual cooling system load (MJ), and
COP_c = seasonal coefficient of performance of the cooling system.

The present worth factor (PWF) can be calculated using a standard financial formula (Stephenson 1976):

$$\mathrm{PWF} = [1 - (1+a)^{-n}]/a \tag{3}$$

where n is the economic life and a is the effective interest rate.

The effective interest rate can be calculated as

$$a = (i - e)/(1 + e) \tag{4}$$

where i is the discount rate or cost of money (including inflation) and e is the rate at which the energy cost is expected to increase (including inflation).

Values for these economic parameters were chosen by each province and territory. While these values did vary, typical assumptions were as follows:

- economic life = 30 years,
- inflation rate = 3%,
- discount rate (including inflation) = 9%, and
- energy cost escalation rate (including inflation) = 3.5%.

This corresponds to a PWF of about 15. A present worth factor of 15 essentially means that it is worthwhile to spend \$15 on construction costs to save \$1 in energy costs in the first year.

The LCC procedure we developed was applied to a range of thermal performance characteristics for building envelope components, such as walls and windows. The following essential elements had to be created for this procedure.

Cost Data Base

The life-cycle cost analysis requires information about the added cost that is involved in producing an increase in the thermal performance characteristic of the envelope component. A construction cost data base was developed for the LCC software. This consists of a table that relates construction costs to thermal characteristics for each type of component to be considered in the analysis. For example, for walls this would be a table of construction costs vs. U-factor. Producing such a table is not trivial because there are many ways of constructing a wall that has a particular U-factor, some more expensive than others. Development of the construction cost data base proceeded as follows.

The first step was to produce a specification for a method of estimating construction costs (EBG 1992) that could be consistently used to estimate costs for a wide range of envelope components. This method focuses on the incremental costs associated with achieving the thermal characteristics, rather than the absolute cost of construction. It accounts for materials cost, labor cost, builder's markup and profit, as well as applicable taxes. A provision also was included to apply regional construction cost modifiers to account for differences in the cost of materials (transportation), labor, and taxes from one region to another.

Next, this methodology was applied to both opaque components (EBG 1993) and windows (EE 1993). A large number of constructions were identified (literally hundreds of different options for windows, walls, roofs, and floors). The thermal characteristics (U-factor for opaque components, U-factor and SHGC for windows) of each were determined and the construction costs estimated using the method described above.

These were then divided into categories, for example, various types of walls and types of roofs. From the large number of constructions in each category, a smaller number were selected to represent that category for the LCC analysis. This subset was chosen to represent a wide range of thermal characteristics. As an example, Figure 1 shows a plot of construction costs vs. U-factor of many construction options for one type of wall (metal studs). This figure illustrates that different ways of achieving a particular U-factor may have different costs.

The representative points were selected to describe the "trend" for relatively low-cost options. High-cost options were eliminated because they would never be chosen in the LCC analysis. Similarly, data points lying well below the trend line were not necessarily used in the analysis. As with any survey, there is more uncertainty

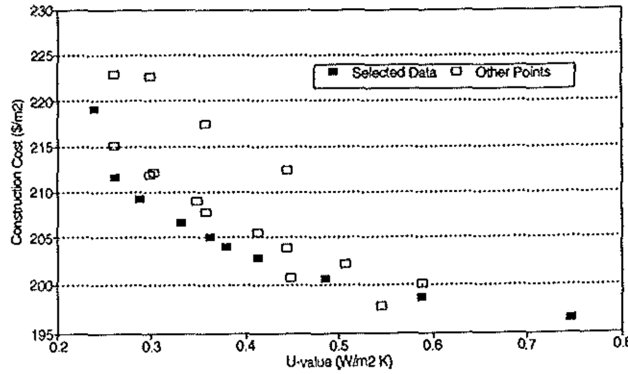

Figure 1 Construction cost vs. U-factor for metal stud walls, showing selection of representative points for LCC analysis. Costs shown are for Ontario, 1993.

associated with the individual points than with a trend formed by many points. Assemblies represented by points far below the trend line would tend to be picked by the LCC analysis over a much broader range of circumstances than normally would be expected, in some cases for the entire range of climate and for all fuel types. This might be acceptable if it is due to some fundamental advantage of the assembly. However, there also is the possibility that the cost is artificially low because of some local and temporal market aberration, or even because of an error in cost estimating. For example, low-e windows are sometimes sold at par with clear glass windows as a promotion, but this does not reflect the long-term incremental cost of the low-e option. Therefore, unless we had an exceptionally high level of confidence in the low-cost point we used only points along the trend line for the analysis on the basis that this would produce requirements that could be satisfied by several different assembly techniques or products on the market and would be less likely to give one particular alternative an undue advantage.

Reference Building Model

A reference building had to be defined for the purposes of performing LCC analysis. This model determines the areas of the envelope components, and hence the incremental construction cost for the building, as well as the energy consumption that results. Because we considered only building envelope options, this model consisted of only four perimeter zones. The assumptions for this building model include:

- square building, all four perimeter zones identical;
- no interzone heat transfer;
- window area is 40% of gross wall area;
- six-day/week office-type schedule;
- internal gains are 25 W/m^2 of floor area;
- infiltration is 0.25 $L/s/m^2$ of wall area;
- ventilation is 9.4 L/s/person;
- VAV system with air-side economizer;

- seasonal heating system efficiency is 70% for oil/gas/propane (100% for electric heat); and
- seasonal cooling COP is 3.0.

Energy Analysis Technique

A method for estimating the change in heating/cooling energy consumption due to a change in the building envelope was developed specifically for this analysis. This method is based on a correlation of the results of a large number of DOE2.1 simulations and is described in a companion paper (Cornick and Sander 1995).

LCC Analysis Software

Software was developed to integrate the elements described above with the evaluation of the life-cycle cost given by Equation 2. This software takes the form of a menu-driven spreadsheet that performs the following steps.

1. Get input from the user. User input includes geographic location, heating energy source, energy prices, and economic assumptions.
2. Generate combinations of envelope components (from the data base) and, for each combination:
   (a) calculate the incremental construction cost of the building using the construction cost data base;
   (b) calculate the heating and cooling system loads using the energy analysis technique developed for this purpose and climate data for the specified location;
   (c) convert the system loads to annual fuel and electricity consumption using assumed heating efficiency and cooling COP;
   (d) convert the annual consumption to annual energy cost using the appropriate energy price for each fuel, as obtained from user input;
   (e) convert the annual energy cost to present value, using the present worth factor computed from economic assumptions input by the user;
   (f) calculate the LCC.
3. Find the combination of envelope components that has minimum LCC.
4. Output the analysis results in the form of graphs and tables.

This analysis selects the combination of envelope components that results in the lowest LCC. The various components, such as walls and windows, are varied simultaneously and the effect on the whole building is evaluated so as to account for interactions between the components. The software reports the combination of components that results in the lowest LCC. However, it often is useful to know how much better the optimum value for a component is than some of the near-optimum alternatives. Therefore, the software also produces graphic output to show how the LCC varies for each component. This variation in LCC for a component is calculated for the condition in which all other components are at their optimum values. Examples of the graphic output of the LCC software are shown in Figures 2 and 3.

APPLICATION AND RESULTS

Initially, the intent was that the LCC procedure could simply be given to the provinces so they could determine the envelope requirements for the regions within the province. Subsequently, it was decided that the national code development group would perform the analysis in consultation with provincial representatives and to publish tables of envelope requirements for the entire country in the NECB. We consulted representatives from government and industry in each province and territory to decide which inputs would be appropriate for each region. These decisions included how the province should be divided into regions, what adjustments should be made to construction costs in the construction cost data base, what energy sources (fuels) should be considered, and what energy prices and economic assumptions to assume for each region.

This generally involved at least two stages. The first was a familiarization stage in which an initial set of assumptions was chosen. The province then spent some time evaluating the results obtained, often with input from industry advisory groups, and modified the input assumptions for a second round of analyses. The second round produced the requirements that went into the first public review draft of the energy code. After public review of this document, some of the assumptions were revised yet again and the process was repeated to produce a second public review draft.

Wall Example

Figure 2 shows an example of the graphical output from the LCC analysis software. This graph is for one type of wall, for natural gas heating, and for the geographic region (Ontario Zone A) that includes southern and central Ontario (e.g., Toronto). The graph shows the incremental life-cycle cost, per square meter of wall, for wall constructions representing different U-factors. These were evaluated for the condition where all other envelope components (e.g., windows) were at their optimum (i.e., lowest LCC) value.

Each bar of the graph is made up of three parts. The incremental construction cost shown is the cost per square meter of wall relative to the lowest cost option. Similarly, the incremental cooling cost is the present value of the cost for cooling per square meter of wall relative to the option with lowest cooling, and the incremental heating cost is the present value of the cost of heating per square meter of wall relative to the option with the lowest heating. The height of each bar is the total incremental life-cycle cost for that option. The bars are in order of

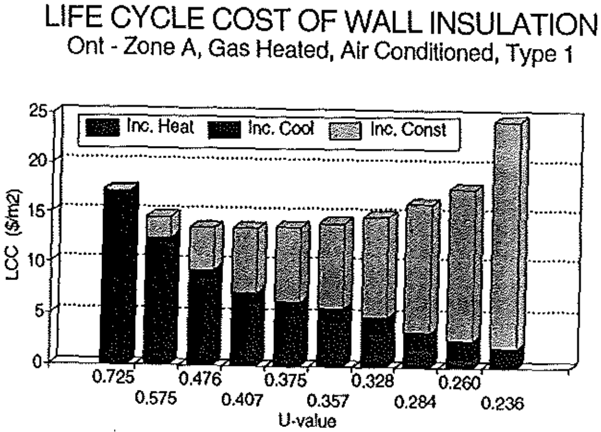

Figure 2 *Output of LCC analysis program for wall insulation, Ontario Zone A, natural gas heating, and economic assumptions used for NECB.*

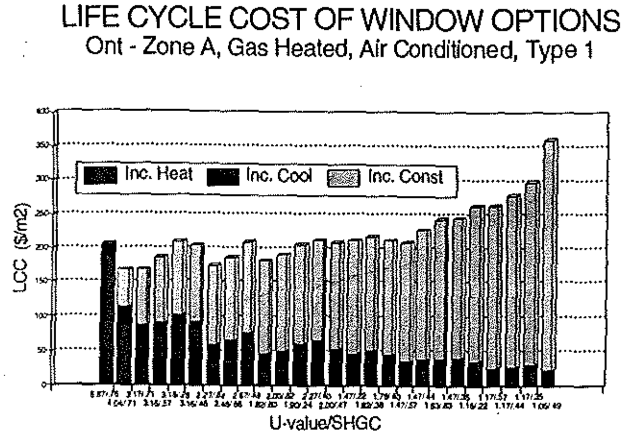

Figure 3 *Output of LCC analysis program for windows, Ontario Zone A, natural gas heating, and economic assumptions used for NECB.*

incremental construction cost; the left bar is the lowest construction cost (i.e., incremental construction cost equals zero).

This figure shows the classic U-shaped curve. It also illustrates that the curve often is quite flat in the region of lowest LCC. This is important because it means that the standing committee had some discretion in selecting code requirements; there actually is a range of U-factors that can be economically justified, not a single value. Figure 2 also shows that the change in cooling has a relatively small impact on the LCC. This was the case for opaque components for all of the Canadian climates.

Window Example

Figure 3 shows an example of the graphical output for one type of window, for natural gas heating, and for Ontario Zone A. This graph shows the incremental life-cycle cost, per square meter of window, for a variety of window constructions. Again, these were evaluated for the condition in which all other envelope components were at their optimum. Unlike walls, there is no single thermal performance characteristic for windows against which to plot the LCC. Each window construction represents a specific combination of U-factor and solar heat gain coefficient (SHGC). Window constructions were chosen to represent the spectrum of combinations available. The order of window constructions shown is in increasing construction cost.

Again, each bar is made up of three parts: incremental construction cost, cooling cost, and heating cost. The lowest LCC option can be seen from the graph, as can the second, third, etc., choices. However, because there is no single parameter for windows, these do not produce a smooth curve as was the case for walls.

Figure 3 shows that the LCC for windows is determined primarily by the construction cost and the heating cost. For all regions of Canada we found that the choice was dominated by heating rather than cooling energy considerations. However, even relatively small differences in cooling cost could "tip the scale" in favor of one window over another, so cooling considerations did play a role. In most cases a decrease in SHGC (tinted glass) increased the heating cost more than it decreased the cooling cost. Therefore, the LCC procedure tended to pick clear glazing options. (The exception to this was where gas prices are low and electricity prices high.)

CONVERSION TO CODE REQUIREMENTS

Walls

It was easy to establish the requirement for wall U-factor based on the lowest LCC from a graph such as that shown in Figure 2. In fact, other considerations sometimes were taken into account by the standing committee but the graph of LCC did provide the economic justification for the choice of required U-factor for the opaque elements.

Windows

Establishing code requirements for windows was not as straightforward. A graph such as that in Figure 3 permits one to choose a specific window, with a specific combination of U-factor and SHGC, that has the lowest LCC. However, we do not wish to restrict code compliance to a requirement for a specific window. We want to permit other combinations of U-factor and SHGC that are just as good as the lowest LCC option. A solution to this was to apply the principle that is used for the trade-off compliance option in the code. This criterion is that a window is permissible if the energy cost (sum of heating plus cooling) is no greater than the energy cost for the reference window (the one having the lowest LCC). Another trade-off criterion is that if the window area is greater than 40% of the gross wall area, then the energy cost must be no greater than would be the case with 40% of the reference

TABLE 1 **Maximum U-Factor Requirement for Windows (W/m²·K), Ontario Zone A, Gas Heat, with Assumptions Used for NECB**

	Window Area (% of gross wall area)			
SHGC	<40%	50%	60%	70%
<= 0.3	2.7	2.3	2.1	1.9
to 0.4	2.9	2.5	2.2	2.0
to 0.5	3.0	2.6	2.3	2.1
to 0.6	3.1	2.7	2.4	2.1
> 0.6	3.2	2.7	2.4	2.1

window. Therefore, for any SHGC we can calculate the U-factor that would give the same energy cost.

Table 1 shows the window U-factors that are equivalent to the reference window for various combinations of window area and SHGC. This is essentially the same as precalculating the combinations of U-factor and SHGC that would just comply with the code using the trade-off procedure. Thus, any window that has a U-factor less than or equal to that given in the table satisfies the code requirements for that condition of SHGC and window area. As one would expect, the columns for higher window area contain requirements for better windows (i.e., lower U-factors). The change of U-factor with SHGC reflects the fact that heating tends to dominate for Canadian climates. Cooling cost does decrease for lower SHGC, but heating is increased and the extra cost of heating outweighs the savings in cooling.

This would not be the case for a climate that requires more cooling or where the cost of electricity relative to the cost of heating was higher. Table 2 illustrates the results for a hypothetical case in which the cooling cost is assumed to be double that for Table 1. The cost of cooling would increase if the price of electricity was increased, the COP decreased, or if no economizer (free cooling with outdoor air) was assumed for the air-conditioning system. In this case, the U-factor of the window can increase for lower SHGC to compensate for the reduction in cooling cost. Notice also that the more expensive cooling increases the penalty for increasing window area. Table 2 illustrates the pattern that would be expected in climates that are less heating dominated than Canada.

In the first public review, concern was expressed about the window requirements in the code. Almost every region showed the pattern illustrated in Table 1; that is, buildings that use low-SHGC (e.g., tinted) glass are penalized. There were objections that this does not send the right message to designers. (There would probably be no such objections if the analysis had resulted in tables that looked more like Table 2.) One of the arguments was that low-SHGC glass has benefits that are not accounted for in the analysis that was used to determine the code requirements. In particular, the analysis does not consider the cost savings from reductions in cooling system size that are made possible with tinted glazing. In recognition of this concern, the window requirements were changed to make the required U-factor independent of SHGC. This means that the code will neither impose a penalty nor provide a credit for SHGC. There is still a penalty for increasing window area above 40% of gross wall area, but the U-factor requirement is based on the criteria that the energy cost should be no greater than if the window area was 40% of gross wall area and the windows had the U-factor of the reference window but the same SHGC as the windows proposed in the design.

TABLE 2 **Maximum U-Factor Requirement for Windows (W/m²·K), Ontario Zone A, Gas Heat, with Assumptions Used for NECB Except that Cost of Cooling (Electric) Is Doubled**

	Window Area (% of gross wall area)			
SHGC	<40%	50%	60%	70%
<= 0.3	3.5	2.9	2.5	2.2
to 0.4	3.5	2.9	2.4	2.1
to 0.5	3.4	2.8	2.3	1.9
to 0.6	3.3	2.6	2.1	1.6
> 0.6	3.2	2.4	1.8	1.3

CONCLUSIONS

The authors have developed an automated procedure to perform LCC analysis on building envelope components, such as walls and windows, for the purpose of establishing values for the National Energy Code for Buildings.

This procedure was then applied, in close consultation with the provinces and territories, to produce requirements that were customized to reflect local construction costs, energy costs, and economic assumptions for 34 different regions of the country. Specific requirements were determined for each significant energy source available for each region. Typically, this resulted in more stringent requirements for buildings heated with an expensive source, such as electricity, than for a cheaper source, such as natural gas. Both input assumptions and results were reviewed by local government and industry groups. The final results of this consultation were then subjected to general public review.

The LCC software proved to be a useful tool for rapidly conducting analyses and presenting the results to the standing committee that made the final decisions on code requirements. The procedure was successful in producing defensible envelope requirements for the Canadian energy code that were customized to reflect regional concerns. Furthermore, the procedure is flexible enough that there should be little difficulty in extending it to other similar applications.

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