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A METHOD FOR LIFE CYCLE COST ANALYSIS FOR THE NEW ENERGY CODE FOR HOUSES

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ABSTRACT

The Canadian Code for Energy Efficiency in New Houses will feature prescribed thermal characteristics of the envelope components of houses. These will be selected primarily on the basis of life cycle cost. A new method was developed to perform the life cycle cost evaluations of energy efficiency options for walls, roofs, windows and basement walls, based on their performance within the energy system of a house. Existing analytic techniques were adapted to perform the energy analysis and life cycle cost calculations . The new procedure allows for regional variations in energy rates, type of heating fuel, economic assumptions and environmental cost multipliers. A prototypical spreadsheet has been developed to perform trial calculations and illustrate typical results. This analytic tool, when approved by the Standing Committee on Energy Conservation in Buildings, will be submitted to the provinces along with the model energy code. The procedure is intended to be used by provincial authorities as a basis for selection of prescriptive values in the Code.

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1.0 INTRODUCTION

The Canadian Code for Energy Efficiency in New Houses will feature prescribed thermal characteristics of the envelope components of houses. These will be selected primarily on the basis of life cycle cost. The following is a description of the analytic procedures and computer model that have been developed to perform the life cycle cost analysis of envelope options for houses. The method and model were developed with the guidance of the Working Group on Calculation Procedures for Houses of the Standing Committee on Energy Conservation in Buildings.

The procedure described herein was developed to evaluate the life cycle cost (LCC) of a range of thermal performance characteristics for walls, roofs, windows and basement walls, based on their performance within the energy system of a house. For envelope options, the incremental life cycle cost has been defined to include two components: the incremental cost of construction and the present worth of the annual heating requirement. Other costs and benefits such as repair and maintenance, capital depreciation and residual value at the end of the evaluation period are assumed not to be affected by the level of thermal performance of envelope components, and thus represent no change to the incremental LCC being evaluated.

The method first requires that a list of energy options be developed and costed for each envelope component. For each option in the list, the incremental LCC is evaluated by finding the sum of the incremental construction cost and the present worth of incremental energy cost. Performing the analysis on a range of options typically results in one option having the lowest LCC in the range. That option would be picked as the value to be prescribed for the component, heating fuel and region.

The analytic procedures that form the proposed LCC analysis method are comprised of two parts:

- the energy analysis technique
- the economic analysis technique

These are described in the following two sections. A third section describes the prototypical spreadsheet that was developed to demonstrate the method and example results.

2.0 THE ENERGY ANALYSIS TECHNIQUE

The energy analysis technique evaluates the annual space heating requirement of a reference house by modelling all of the essential elements of the house's energy systems. The whole-house performance evaluation is done for each option and each envelope component of the house. The change in space heating requirement of the house associated with a change in the thermal characteristic of a component is the incremental heating cost of that option relative to a reference. The analysis technique is based on two methods developed at NRC for evaluating the heating performance of houses:

- a single-zone, month-by-month energy analysis technique that accounts for internal gains, solar gains and heat loss through the envelope. This is referred to as the "Gain Load Ratio" technique, GLR (1). The weather data used in the calculation consist of mean monthly outdoor temperatures and solar radiation.
- a method for below-grade heat loss estimation, referred to as the Mitalas method (2)

The analysis technique consists of estimating on a monthly basis:

- the gross heat loss of a reference house, including all conduction and air leakage losses of above grade components, and heat loss of on-grade or below-grade components through the soil
- the usable internal gains from electricity use and occupant activity
- the usable solar heat gains through windows

The net monthly heating requirement is found by subtracting the sum of all net gains (internal and solar) from the sum of all gross heat losses (above grade conduction, air change and below grade heat loss). The reference house is treated as a single zone for the summation of losses and gains. The seasonal heat loss is the summation of the monthly results over the heating season. For the purposes of the energy code, a heating season has been defined as those months for which the mean monthly temperature falls below 11°C. This criterion results in reasonable predictions of heating season duration across the country, and it was thus selected on that basis. The 'heating season' was defined to exclude summer months from the energy analysis, when houses are operated differently than during the heating season.

The algorithms used in this energy analysis technique are similar to those used in HOT2000 (3), the computer program used to show compliance for R-2000 certification. However, they are implemented here to meet the specific needs of the energy code, including refinements described below.

2.1 Regeneration of the GLR Algorithm Correlations

Discontinuities were found in the original algebraic expressions developed for the GLR technique. Although these have little impact on seasonal heat loss prediction, significant errors could be introduced when using the published expressions to evaluate the effect of a small change in the thermal characteristic of a component, which is what the technique is used for in this context. These errors would produce incorrect predictions of energy savings at those points.

As well, solar and mass effects which are handled by correlations developed in ref. 1 were originally correlated based on five discrete levels of internal mass expressed as ratios to solar gain. The approach of using the next nearest correlation for the appropriate mass/gain ratio (MGR) had resulted in discontinuities in savings estimates associated with changes in the solar transmission characteristic of windows. New expressions were developed for the correlations, and linear interpolation was used between MGR curves, to assure continuity in the savings estimates for all combinations of envelope and window characteristics. The new expressions for the GLR correlations are recorded in ref. 4.

2.2 Specification of Reference House Characteristics

The energy analysis technique described above is used to evaluate the change in energy performance of a house due to changes in individual component characteristics. To perform these evaluations, an appropriate reference house needs to be defined. A sensitivity analysis was undertaken to help in the selection of the reference house characteristics. The objective of the analysis was to determine whether reasonable variations in the essential characteristics of the reference house would cause significant variation in the prediction of differential energy use ascribed to an energy option. It was found that although all elements of a house design can influence the savings associated with a particular component upgrade, this influence is relatively small in most cases. Typically, reasonable variations in house style, size, internal and solar gains, etc., resulted in differences in savings of the order of ±2%, when the savings were normalized per unit area . It was concluded that the particular assumptions made about the reference house would not bias the results significantly, especially if the selected characteristics were closer to the average than to an extreme. Details of the sensitivity analysis are reported in ref. 5.

The main characteristics of the reference house were selected as follows:

- a 2-storey house with 160 m^2 livable area and full basement . (House models featuring a crawl space and a slab-on-grade foundation have also been defined to accommodate those regions that have large numbers of these types of foundations).
- the internal heat gains were set at 20 kWh per day
- windows were assumed to be distributed evenly around the house, with a rough opening area equal to the maximum that will be allowed by the energy code: 20% of floor area. Windows were assumed to be partially shaded from the sun. The shading effect was applied evenly to all orientations and was handled by treating the shaded portion of the glass area as if it were north facing; i.e., shaded portions receive mostly diffuse solar radiation.
- a seasonal average air change rate of 0.40 ach was specified. This total is comprised of air leakage amounting to 0.25 ach - based on the results of the 1989 nationwide survey of airtightness of new houses (6) - and a balanced and continuous ventilation rate of 0.15 ach, included to meet the intent of CSA F326(7).

All of these features are held constant in the LCC analysis, including air change rate.

2.3 Space Heating Cost

The annual space heating requirement evaluated by the above technique is divided by the furnace efficiency. For electric resistance heating the efficiency is set to 100%. For heating with gas and oil, the seasonal efficiency is set to 78%, to be consistent with minimum efficiency requirements for residential heating appliances that will be set by the applicable energy efficiency acts when the code comes into effect. The calculated fuel energy requirement is then converted to a volumetric quantity using the appropriate conversions, and is multiplied by the applicable regional fuel price. Provision has also been made to include an environmental cost multiplier. This multiplier, if implemented, would increase the apparent annual cost of space heating to reflect hidden environmental costs associated with fuel usage. The resulting number is the total annual cost of space heating for the reference house for a given fuel and location.

3.0 THE LIFE CYCLE COSTING TECHNIQUE

Based on an assessment of information needs and on a review of the type of information generated by existing life cycle cost programs, including CMHC-2 (8) and ARES (9), the following statement of objective was developed for the proposed life cycle costing technique:

> For a given set of economic assumptions and energy rates, a range of thermal options and corresponding incremental construction cost, the technique must be able to generate and display the incremental life cycle cost of each option in the range, and highlight the best option on the basis of lowest life cycle cost. Of primary importance is the need to provide for each option enough costing information, including construction cost increment, such that confidence can be developed about the appropriateness of the selection.

3.1 Description of the Proposed Method

A number of economic assumptions have to be made to determine the life cycle cost of an option. Although the selection of economic assumptions plays an important role in the outcome of the calculation of life cycle cost, their selection will ultimately be in the hands of the provincial authorities having jurisdiction. Table 1 lists a number of economic assumptions that are consistent with those used to develop the '83 Measures (10).

The assumptions in the table result in a present worth factor* of 18. The seasonal heating cost is

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* - the present worth of annual heating costs is the sum of money, which if deposited in a bank or invested in an annuity, and withdrawn to pay for annual heating costs, would just be consumed (both principal and interest) at the end of the period under consideration. The present worth factor is the ratio of the present worth to the heating cost in the first year (10).

multiplied by the present worth factor to obtain the present worth of heating energy (PWE). The PWE is evaluated for all options in a list. The PWE of the best option in the list is then subtracted from all PWE's to produce the incremental PWE. This value is added to the incremental cost of construction of the option being evaluated, yielding the total incremental life cycle cost of heating (LCC) of that option. All quantities are normalized per unit area of the component being analyzed.

Table 1. Example Set of Economic Assumptions

General Inflation Rate	5.0%
Interest above Inflation Rate	3.9%
Fuel Escalation above Inflation	0.0%
Discount Rate	3.7%
Economic Life	30 years

Figure 1 illustrates the results of such a calculation for the wall of an electrically heated house in Vancouver. The height of the dark bar represents the present value of the additional cost of heating for each unit of wall thermal resistance (RSI). The wall with the largest RSI in the range has no additional energy cost since this is automatically the reference. The light bar represents the increased cost of construction relative to the lowest cost in the range. The sum of the two quantities has been defined as the normalized incremental life cycle cost of each option - the total height of the bars. In this example, RSI 3.7 has the lowest incremental LCC and would likely be selected by code authorities; however, a number of other options have similar LCC's and their selection could be justified for other reasons.

The optimization consists of an iterative technique to find the lowest LCC option of each component, i.e., walls, roofs, windows and basement walls. The first evaluation uses the lowest thermal characteristics in each range to specify the reference house. In a second step, it re-evaluates the lowest LCC's using the optimized options of the first step in the reference house. In a third step, the procedure does a final check on the lowest LCC's to ensure that these have not changed using the results of the second iteration. This procedure ensures that the final result for each component is based on the energy analysis of a whole house having envelope components with optimized levels of thermal efficiency. Details are included in ref. 4.

4.0 APPLICATION AND RESULTS

4.1 The Computer Model

A spreadsheet was developed using a commercially available programming environment. The prototypical model, called LCCH (Life Cycle Costing for Houses), incorporates the energy analysis and life cycle costing techniques described above. The spreadsheet allows the user to perform the following functions through menu selections:

- select house type and foundation type
- select location
- select fuel type with corresponding fuel cost
- edit economic assumptions
- perform the life cycle cost analysis
- present the results in graphical and tabular form, and
- print the results

The presentation of incremental LCC in graphical form is a key feature that permits a comparison of the relative costs of each option, thereby facilitating an informed selection.

To illustrate the method, a preliminary list of options for walls, windows and basement walls were evaluated for an electrically heated house in Vancouver. Roof options can also be evaluated by the method but are not shown here for the sake of brevity. The LCC of envelope airtightness levels is <u>not</u> evaluated in this procedure.

4.2 Walls

Canadian insulation manufacturers were consulted to identify standard construction practices for achieving various RSI levels. Literally hundreds of combinations were identified as a result of the fact that many insulation products are available in 3 mm (1/8 inch) increments. To rationalize the number of options to be analyzed - and ultimately to rationalize the numbers of different thicknesses of products that need to be manufactured and kept in inventory - it was decided to slot the various products into categories of RSI in increments of RSI 0.2. Within each category, a number of products were costed and the one with the lowest incremental cost was used to represent the RSI category. The resulting incremental construction costs are shown by the light portions of the bars in Fig. 1, as discussed above.

The energy performance associated with these options were then analyzed and the incremental present worth evaluated. This resulted in the incremental present worth of heating costs shown by the darker portions of the bars in Figure 1. The sum of these two components were plotted as shown and a minimum LCC was identified for RSI 3.7; e.g. typically an insulated 140 mm cavity wall with 19 mm extruded polystyrene. Because many options feature LCC's that were the same or close to optimum LCC identified in this example, several adjacent options could be justified on the basis of LCC.

4.3 Windows

Windows manufactured in Canada can now be characterized by an overall heat transmission coefficient, U, and solar heat gain coefficient, F, which are combined into an energy rating, ER, according to the new standard CSA A440.2 (11). The standard will be referenced in the new energy code. The availability of these thermal characteristics proved to be very useful when applied to the LCC procedure. The U and F characteristics are used directly in the energy analysis method to determine thermal performance of the windows in the reference house. A window airtightness level is assumed (and kept constant for all options). The ER is calculated based on the three characteristics and is used to label the results, as illustrated in Figure 2. In this example, the optimum ER is identified to be -12; e.g. typically a double glazed unit with one low emissivity coating. ER numbers will be used to specify minimum levels of performance for windows in the energy code.

4.4 Below Grade Walls

The use of the Mitalas method in the procedure has allowed the evaluation of the LCC of a number of insulation placement schemes for basement walls in the energy code. An example evaluation is shown in Fig. 3. For the cost assumptions made in this example, the full depth insulation options showed the better LCC's. In areas where cheaper sources of energy are used, this advantage is not so clear cut.

4.5 Environmental Cost Multipliers

One of the requirements of the procedure for determining levels of energy efficiency in the new energy code is that it be capable of accounting for environmental costs associated with energy generation and use. This has been introduced into the life cycle cost calculation as a multiplier on the energy cost for each heating fuel, as explained above. These multipliers are currently set to 1. Federal and Provincial policy on the environment; e.g., a carbon tax, will dictate what multipliers will eventually be used.

A range of cost multipliers were tried for houses heated with gas in Vancouver. The effect of the multiplier on the selected RSI; i.e., the one with the lowest LCC, is shown in Fig. 4 for walls and roofs. The result for roof insulation is a continuous curve, since a blown insulation product was selected for the example. The walls are insulated to discrete thicknesses of insulating sheathings resulting in the steps in the curve. It can be seen that large multipliers are needed to shift the levels upward to a significant degree. Typically, environmental multipliers being suggested today are less than 1.5.

5.0 CONCLUSION

A method has been developed and documented for performing life cycle costing of thermal options for the envelopes of houses. This was done in support of the Canadian Code for Energy Efficiency in New Houses. Existing analytic techniques were adapted to perform the energy analysis and life cycle cost evaluations. The analysis consists of a life cycle cost evaluation of discrete constructions for each component. A prototypical spreadsheet has been developed to perform trial calculations. The new calculations allow for regional variations in energy rates and type of heating fuel, economic assumptions and environmental cost multipliers. A similar set of procedures is under development for buildings other than houses.

Initial trials of the procedure indicate that showing the LCC and its two component costs for each option in graphical manner allows judgment to be introduced into the selection process. This appears to be worth while since there may not be a clear cut option for some components and other considerations may override; e.g. the result for walls in the example shown. In other situations where the choice is more obvious, e.g., the basement wall example, a level of confidence can be developed with the selection based on the difference between it and the nearest option. Finally, the environmental cost multiplier can be used as a policy instrument by making adjustments on the envelope levels to be prescribe in the energy code.

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