OPTIMIZE 3.1

A Spreadsheet Application for Estimating the Life-cycle Energy, Material Flow, Environmental Impact and Costs of Residential Buildings and Assemblies.

USER'S MANUAL

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OPTIMIZE

OPTIMIZE is a Canadian data base and spread sheet application for estimating the lifecycle energy, material flow, environmental impact and cost of residential buildings and assemblies. It is intended to assist researchers and designers in optimizing house performance by considering environmental externalities at the same time as other factors related to house design. For example, the choice of a particular building material could be influenced by the amount or type of waste it generates, or the energy consumed in manufacturing.

Techniques for analyzing the energy requirements of housing have been evolving since the early 1970's. The primary focus has been on the reduction of operating energy requirements - i.e., heating and cooling loads, and the energy used by lights and appliances. Much less attention has been given to the embodied energy of houses. Embodied energy refers to energy required to extract the raw or recycled materials used for building houses, the processing of these materials, their transportation, secondary fabrication, and installation on-site.

"Lifecycle" embodied energy expands the analysis to include embodied energy used throughout the lifecycle of a building, including the energy for maintenance, repair and replacement of building components, and the energy required to demolish and haul away the structure at the end of its lifetime.

As operating energy is decreased, the lifecycle embodied energy has become a larger and more significant proportion of the total energy.

Although the analysis of embodied energy in houses is not new, it is a topic of increasing relevance. Limitations imposed by concerns about environmental impacts have emphasized the need to reduce total energy consumed by the residential building sector. In Canada, this sector now accounts for over 18% of the nation's energy demand. The intention of the OPTIMIZE spread sheet is to thoroughly track the energy transformations caused by residential building, and by so doing, to better gauge the environmental impact of a particular houses or building assembly.

Energy transformations are a particularly useful surrogate for environmental impact. Firstly, energy inputs are readily measurable, and have already been thoroughly quantified by industry and catalogued by Statistics Canada. Secondly, energy transformation in closely tied to the environmental impacts with which we are primarily concerned. For example, the combustion of fuels accounts for over 90% of the air emissions in Canada for CO_2, NO_2 CO and SO_2.

The approach adopted for OPTIMIZE has largely followed conventions and techniques developed by other researchers in the field of energy analysis. In addition to the energy

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analysis, OPTIMIZE also analyses the environmental impact of a building by quantifying many of the outdoor and indoor air emissions associated with building products. The outdoor emissions are largely a factor of the combustion of fossil fuels, although the facility exists to also consider the important non-energy related emissions generated as part of the production process. For example, data can be entered for pollutants such as CFCs and particulates.

Indoor pollutants have become increasingly a concern in the last few years, but emissions have been difficult to quantify. In part this is due to a lack of knowledge about the quantities and types of materials involved. OPTIMIZE keeps track of any materials in a building that might contribute significant amounts of VOCs indoors, based upon the percentage of specific materials left exposed to the interior living spaces. OPTIMIZE also calculates the total emission rates and concentrations for nine of the most prevalent VOCs. Default rates for exposure of materials, and emission rates, are based on the research literature and the IAQ computer model. These default values can be adjusted by the user if desired.

OPTIMIZE

OPTIMIZE est une application canadienne tenant lieu à la fois de base de données et de tableur qui évalue l'énergie intrinsèque du cycle de vie, le flux des matières, l'impact sur l'environnement et le coût des bâtiments résidentiels et ensembles de construction. Elle vise à permettre aux chercheurs et concepteurs d'optimaliser la performance des maisons en envisageant les externalités environnementales en même temps que d'autres facteurs touchant la conception de maisons. À titre d'exemple, le choix d'un matériau de construction particulier peut être influencé par la quantité ou le genre de déchets qu'il produit ou d'énergie qu'il consomme au cours de sa fabrication.

Les techniques d'analyse des besoins énergétiques des habitations ont connu une évolution depuis le début des années 1970. Elles avaient pour objet premier la réduction des besoins d'énergie de fonctionnement imputables au chauffage et au refroidissement, de même qu'à l'éclairage et aux appareils. Beaucoup moins d'attention a été portée à l'énergie de production des maisons. L'énergie de production s'entend de l'énergie requise pour extraire les matériaux bruts ou recyclés utilisés pour la construction de maisons, le traitement de ces matériaux, leur transport, la fabrication secondaire, et leur mise en oeuvre.

L'énergie intrinsègue du «cycle de vie» élargit le cadre de l'analyse pour inclure l'énergie de production utilisée durant tout le cycle de vie du bâtiment, y compris l'énergie consommée à des fins d'entretien, de réparation et de remplacement de composants de bâtiment, ainsi que l'énergie requise pour démolir ou se départir du bâtiment au terme de sa durée utile.

À mesure que décroît l'énergie d'exploitation, l'énergie intrinsèque du cycle de vie devient une partie plus importante de l'énergie totale.

L'analyse de l'énergie de production des maisons n'a rien de neuf, mais il s'agit d'un sujet qui accapare de plus en plus d'intérêt. Les restrictions imposées par le souci de protéger l'environnement font ressortir la nécessité de réduire la quantité totale d'énergie que consomme le secteur de la construction résidentielle. Au Canada, ce secteur accapare plus de 18 % de la demande énergétique globale. L'intention du tableur OPTIMIZE consiste à repérer à fond les conversions d'énergie causées par le bâtiment résidentiel, et en ce faisant, à mieux mesurer l'impact sur l'environnement d'une maison ou d'un ensemble de construction particulier.

Les conversions d'énergie s'avèrent un substitut particulièrement utile de l'impact sur l'environnement. D'abord, les apports d'énergie sont facilement mesurables et ont déjà été quantifiés à fond par l'industrie et répertoriés par Statistique Canada. Puis, la conversion d'énergie est étroitement liée aux répercussions sur l'environnement desquelles nous nous préoccupons principalement. Par exemple, la combustion de carburants représente plus de 90 % des émissions de CO_2, de NO_2, de CO et de SO_2 rejetées dans l'air au Canada.

La démarche adoptée à l'égard d'OPTIMIZE a largement suivi les conventions et les techniques mises au point par d'autres chercheurs dans le domaine de l'analyse énergétique. En plus de cela, OPTIMIZE analyse également l'impact d'un bâtiment sur l'environnement en quantifiant bon nombre des émissions dans l'air extérieur et intérieur associées aux produits de bâtiment. Les émissions extérieures sont largement le fait de la combustion de combustibles fossiles, bien qu'une fonction permette aussi d'envisager les importantes émissions non reliées à l'énergie produites au cours du procédé de fabrication. À titre d'exemple, les données peuvent être emmagasinées pour les polluants comme les CFC et les particules.

Les polluants intérieurs sont de plus en plus devenus une source de préoccupation ces dernières années, mais les émissions ont été difficiles à quantifier. La situation est attribuable en partie au manque de connaissances concernant les quantités et les types de matériaux en cause. OPTIMIZE tient compte de tout matériau du bâtiment susceptible de rejeter d'importantes quantités de COV à l'intérieur, d'après le pourcentage de matériaux précis laissés exposés au cadre de vie intérieur. OPTIMIZE calcule aussi le taux total d'émissions et les concentrations de neuf des COV les plus répandus. Les taux implicites d'exposition des matériaux, et les taux d'émissions, sont fondés sur la documentation de recherche et le modèle informatique portant sur la qualité de l'air intérieur. L'utilisateur peut à son gré modifier ces valeurs implicites.

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1. Chapter One: Introduction

1.1 Welcome to OPTIMIZE 3.1

OPTIMIZE is a spreadsheet application designed to assist building researchers and designers in estimating the life-cycle energy, material flows and environmental impact of residential assemblies and buildings. The original version of OPTIMIZE was developed in 1990. Extensive information on life-cycle analyses of residential buildings may be found in the original OPTIMIZE documentation.

OPTIMIZE 3.1 is an updated version of the original program, with more accurate and up to date data, and improved input and results screens. Unfortunately, the new version has retained much of the original program architecture. As a result, OPTIMIZE 3.1 provides a convenient method for obtaining accurate energy and environmental information, but uses a program structure that has become rather cumbersome and unwieldy.

Users familiar with previous releases of OPTIMIZE should note that changes to the data and functioning of OPTIMIZE 3.1 are significant, and it is recommended to treat this version as if it were a new program. All questions about the OPTIMIZE 3.1 program and documentation should be directed to the CMHC.

1.2 User Manual Layout

This guide is organized into the following sections:

- Chapter Two, *Getting Started*, deals with loading Optimize on your system.
- Chapter Three, *The Basics*, describes the overall structure of OPTIMIZE, how to input data and run the program.
- Chapter Four, *Results*, describes the output from OPTIMIZE.
- Appendix 1 provides sample output from OPTIMIZE 3.1.

Throughout this guide, important information is highlighted as follows:

Note: *This highlight indicates information the user should know about or suggestions to facilitate efficient work.*

Chapter Two: Getting Started

2.1 System Requirements

To run OPTIMIZE, the minimum system requirements are:

- Microsoft Excel 5.0, Release C,
- 8 Megabytes of RAM,
- 3.2 Megabytes of disk space on your hard drive, plus an additional 200 Kilobytes of space for each house or assembly file .

2.2 Loading OPTIMIZE on your System

To load the OPTIMIZE program on your computer for the first time:

- create a directory on your hard drive called C:\Opt,
- copy OPTIMIZE from the floppy disk onto your hard drive,
- while in C:\Opt, type OPTIMIZE.

The program is self-extracting and will take a few moments to decompress. The directory should contain two files;

- The OPTIMIZE 3.1 spreadsheet (OPTIMIZE.xls),
- A sample input file called sthouse.opt.

The file sthouse.opt is an input file of a Canadian single family "standard house". Using this file produces sample run output presented in Appendix 1. A description of the house may be found in Chapter 4.

Note: *When using OPTIMIZE 3.1 in design work, it is frequently easier to use sthouse.opt as an archetypal building and alter the input file rather than create an entirely new input file.*

2.3 Program Structure

The structure of OPTIMIZE 3.1 is presented in Figure 1. The application consists of one large workbook which is comprised of a number of linked worksheets. The program is menu driven, allowing for simple movement throughout the worksheets. The OPTIMIZE Menu is the root menu. From here, data may be input, parameters may be defined, the program may be run and results may be accessed. All these options are covered in detail in Chapter Three.

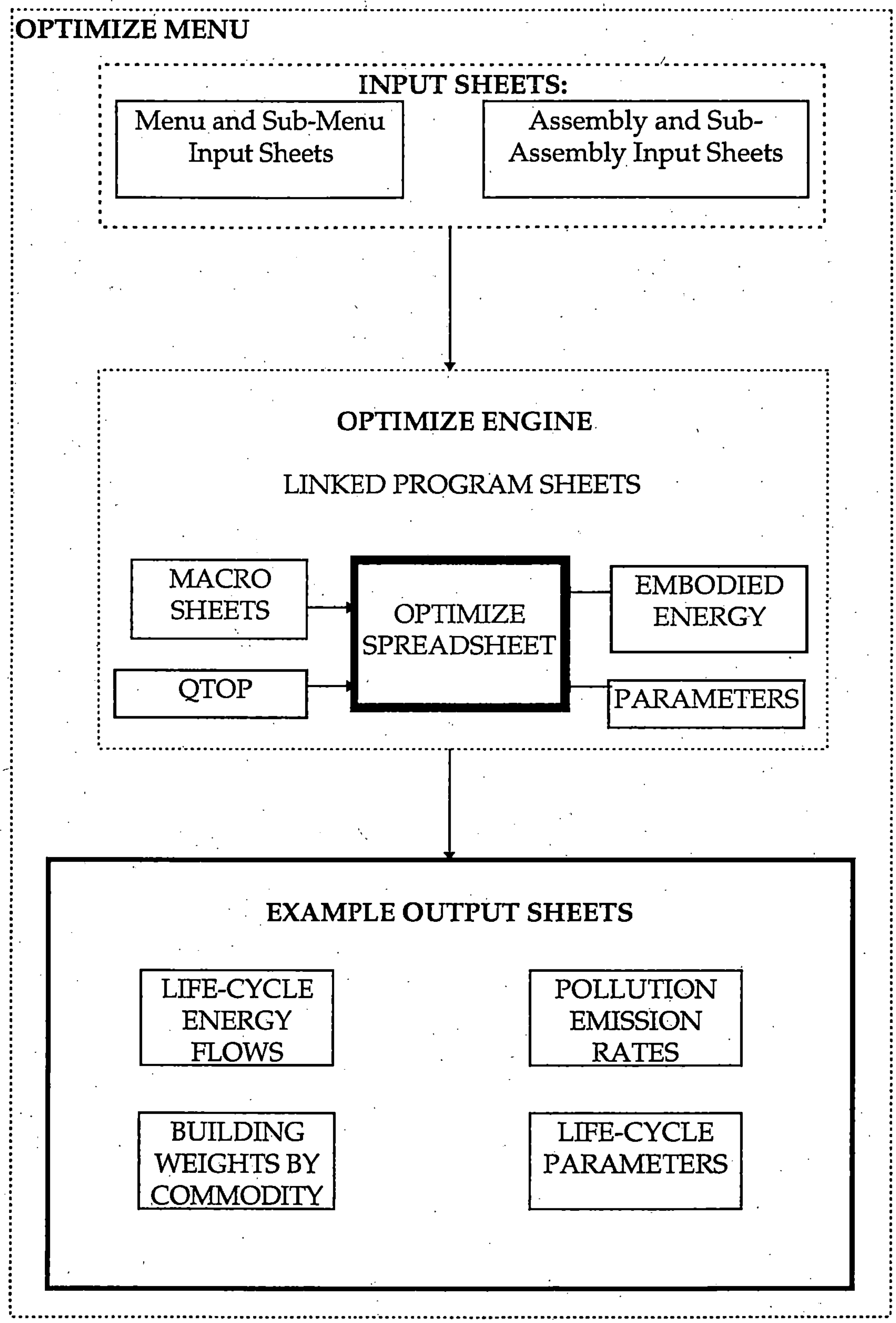

Figure 1: OPTIMIZE 3.1 Program Structure

Chapter Three, The Basics

3.1 Starting OPTIMIZE 3.1

To begin OPTIMIZE, start Excel. Using the File Open command, choose OPTIMIZE.xls and click the OK button. Depending on your system, OPTIMIZE 3.1 may take five to ten minutes to load.

Note: *When OPTIMIZE starts, a dialog box may appear asking if links should be re-established.* **Click the No button.**

Figure 2. shows the initial OPTIMIZE Menu Screen that appears when the program starts.

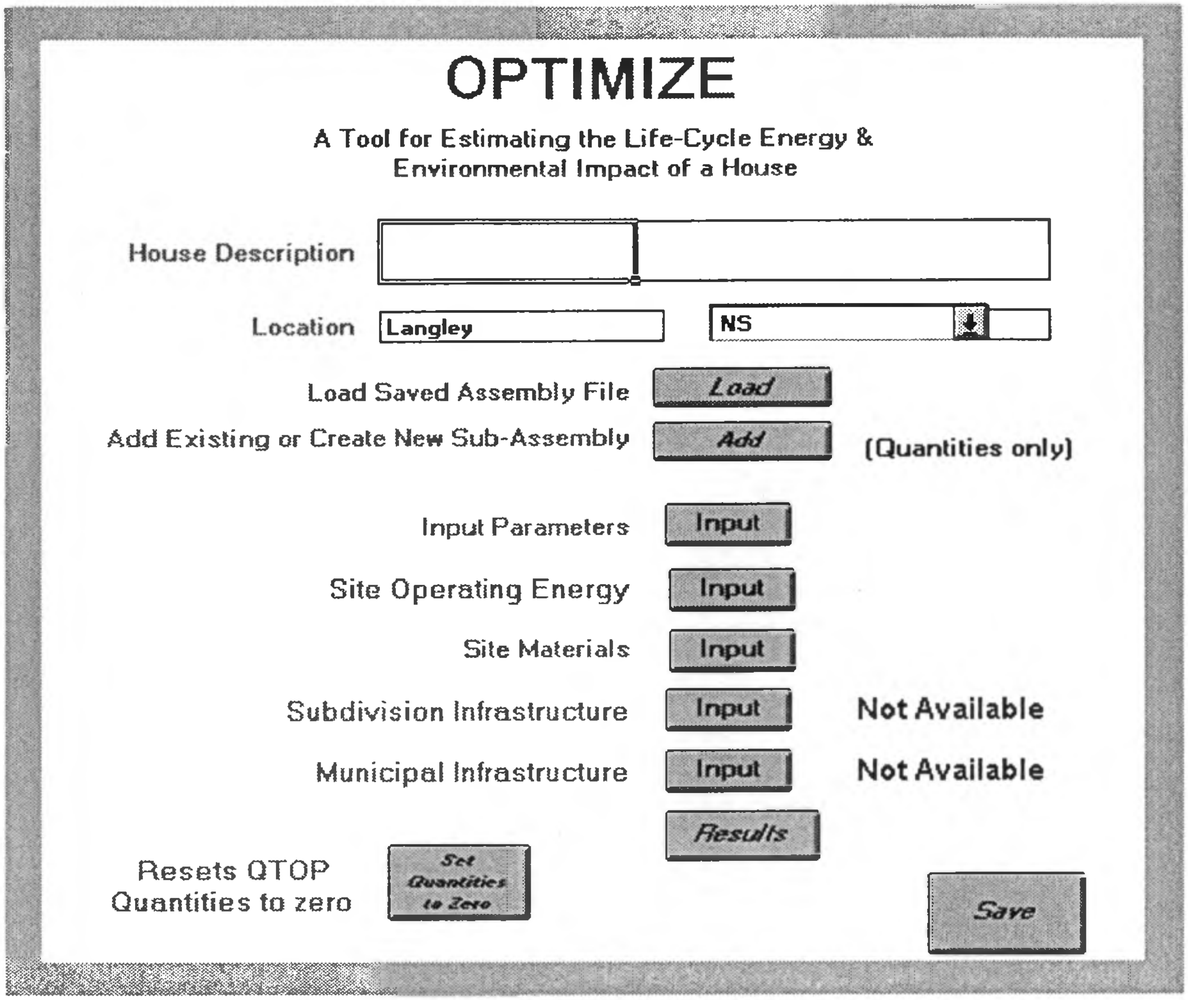

Figure 2: The OPTIMIZE Menu Screen

3.2 Using OPTIMIZE 3.1

OPTIMIZE is a spreadsheet designed to assist building researchers and designers to estimate the life-cycle energy, material flows environmental impact, and cost of residential assemblies and buildings. To obtain meaningful results from OPTIMIZE 3.1, accurate input is essential. The user must input information related to:

- type and quantity of building material used,
- building location,
- building size,
- operating characteristics of the building,
- assumed life,
- financial discount rate.

OPTIMIZE is a large and complex program but is simple to use. The program uses buttons that reference sub-menus, sheets or sections of sheets. This enables the user to input data, process information and obtain results in a way that is highly structured, efficient and clear.

The OPTIMIZE Menu Screen (Figure 2) is the initial screen that appears when OPTIMIZE starts. Clicking on one of the buttons from the menu screen will bring up a sub-menu. The sub-menu will be either:

- a third level menu with buttons to choose from, or
- a data input screen.

To return to the OPTIMIZE Menu Screen, click the *Done* Button at the lower right hand corner of the screen. To input data, type in the input fields provided.

Note: *Example 1 in Section 3.3.10 illustrates how to input data.*

It is not required to input data in any specific order. However, following the order provided by the input menus is the most natural way to move through the program. In order to keep track of data input, the button font colour changes from blue to red once a sheet has been accessed. Simply by viewing the colour of buttons, it becomes possible to quickly identify unaccessed screens where data has not been entered.

3.3 Moving Around OPTIMIZE 3.1

This section describes the function of the menus, buttons and fields in OPTIMIZE 3.1.

3.3.1 The OPTIMIZE Menu Screen

The OPTIMIZE Menu Screen is the root menu which appears when OPTIMIZE 3.1 starts. From this menu, the user may input data, save and retrieve files, calculate results and obtain output.

3.3.2 House Description Field

The House Description field permits the user to input a convenient description.

3.3.3 Location Field

Location consists of two fields; the City field and the Province location field. The City field is an optional input. The Province location field is a pull-down menu which contains the Canadian Provinces and Territories. The Province location field is used to define the primary fuel mix for electricity to be used in OPTIMIZE calculations.

3.3.4 Load Saved Assembly File

This button allows the user to retrieve previously saved assembly files. This is a useful feature of OPTIMIZE 3.1 as most buildings are composed of a system of well defined assemblies or sub-assemblies. Usually it is less confusing and faster to modify existing building files than to create new ones.

Initially, OPTIMIZE does not offer a library of pre-defined assembly files, only a single standard house. However as the user creates assemblies, these become a library for future use, and the utility of the program improves. Ultimately it becomes easy to create new assemblies simply by loading a similar assembly file, and then making appropriate modifications.

3.3.5 Add Existing or Create New Sub-Assembly

The button for "Add Existing or Create New Sub-Assembly" can be used to access a library of **sub-assemblies**. Note that a sub-assembly includes only the quantities of materials for the Quantity Take-off, whereas an **assembly** file includes all the other user variables such as product cost and lifetime. Each sub-assembly is a record in a list which is updated every time a new sub-assembly is saved.

By creating sub-assemblies, it becomes easier to build new assemblies without going through the tedious process of defining quantities of materials in the material input sheets. Instead, an assembly can be built up by selecting and combining a number of existing sub-assemblies, and/or by choosing multiples of a single sub-assembly.

For example, if the user has previously defined the composition of a square foot of floor for one sub-assembly, and a linear foot of wall in another, and a square foot of ceiling in a third, it becomes simple to create a new sub-assembly for the entire room or addition by simply adding multiples of each of these. Add, for example, 1000 units of the floor sub-assembly (equivalent to 1000 square feet of floor materials), to 1000 units of ceiling, to 60 units of wall. The result is a quantity take-off that includes material for an entire house addition.

3.3.6 Subdivision Infrastructure and Municipal Infrastructure

The Life-cycle energy and Environmental impacts of Subdivision and Municipal infrastructure materials are not currently available in OPTIMIZE 3.1.

3.3.7 Reset QTOP Quantities to Zero

The Reset button resets the material quantity inputs to zero. The reset button does not affect the internal variables in OPTIMIZE other than quantities.

3.3.8 Input Parameters

The Input Parameters button shifts the program from the OPTIMIZE Menu to the Parameters sub-menu, shown in Figure 3. The Parameters worksheet allows input of information related to:

- Life of Building,
- Financial discount rate,
- Transportation and energy intensity of variables related to construction, maintenance and demolition.

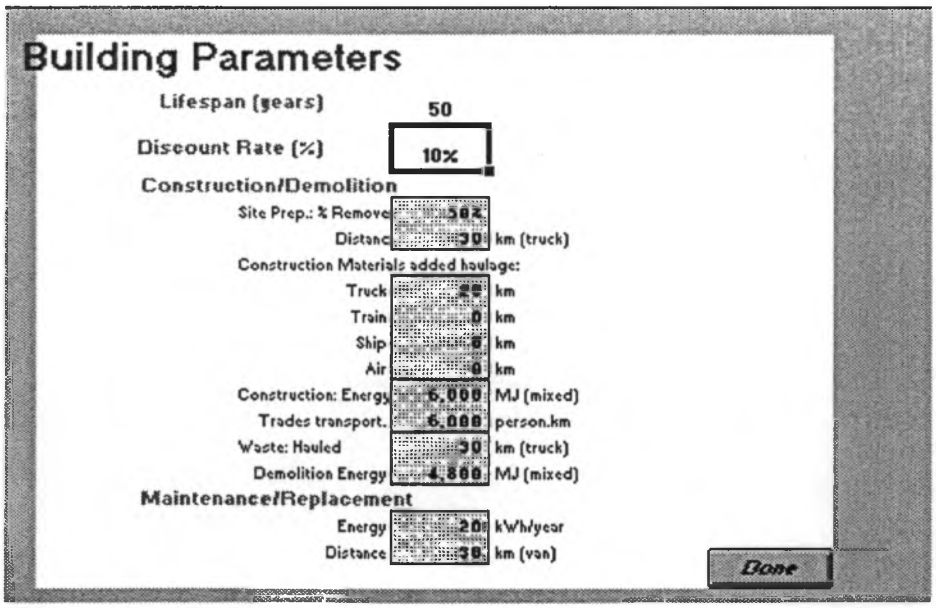

Figure 3. Parameters Worksheet

3.3.9 Site Operating Energy

The Site Operating Energy button brings up the sub menu (see Figure 4.) to input the operating characteristics of the building. In order to calculate the operating characteristics of a building, the user must use a separate program such as HOT2000 or DOE. The primary mix for electricity used in OPTIMIZE is based on Provincial averages, and is automatically input when the user inputs the location of the building.

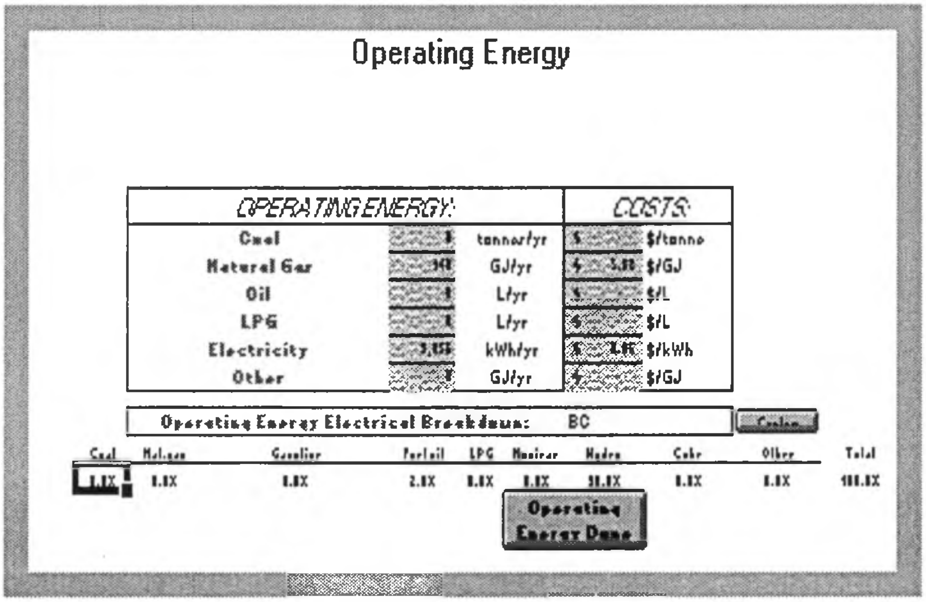

Figure 4. Site Operating Energy

3.3.10 Site Materials

Most of the time and effort required to input a building description occurs in the Site Materials sub-menu. From within this menu, further sub-level menus are invoked to complete a materials take-off for the building. The Site Materials Menu is shown in Figure 5. This menu is organized according to the Masterformat system of classification developed by Construction Specifications Canada (CSC). From this menu, the user inputs material quantities according to the classifications:

- Site Work;
- Concrete;
- Masonry;

- Metals;
- Carpentry;
- Insulation and Moisture Protection;
- Doors, Windows and Finishing Hardware;
- Finishes;
- Specialties;
- Cabinets and Appliances;
- Mechanical; and,
- Electrical.

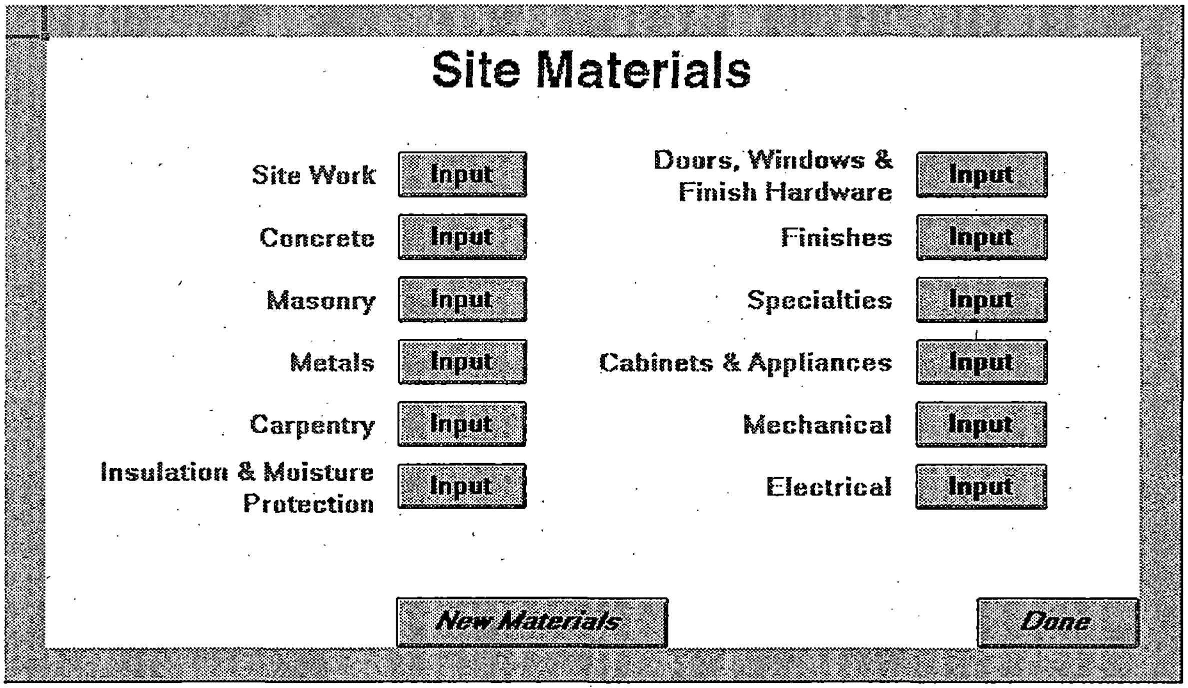

Figure 5. Site Materials Sub-menu

The following example is included to clarify the procedure for inputting data into the Materials Sub-menu. The features and methodologies for inputting data into each of the above classifications is identical.

Example 1: Inputting Building Materials Information.

To review the process for inputting materials information, an example is presented step-by-step for a basement slab.

- In Site Materials, the Concrete button is pressed. This screen is shown in Figure 6.
- Next, the cast-in-place button is pressed to get to the input menu for cast-in-place concrete, as shown in Figure 7.
- Clicking on the Item button, a pop-down list appears.
- Clicking one choice (basement slab in this example), automatically inputs cost, weight, replacement interval and waste factor.
- The user must then input (in the correct builder's unit) the amount of material used. In the current example, 15 cubic yards of concrete are required for the basement slab.
- The user may continue to input data related to cast-in-place concrete from this menu, altering the default values provided by OPTIMIZE. Alternately, by pressing the "Done" button, the user returns to the previous screen.

Note: *Pressing the "Done" button at the bottom right corner of each menu returns the user to the previous screen.*

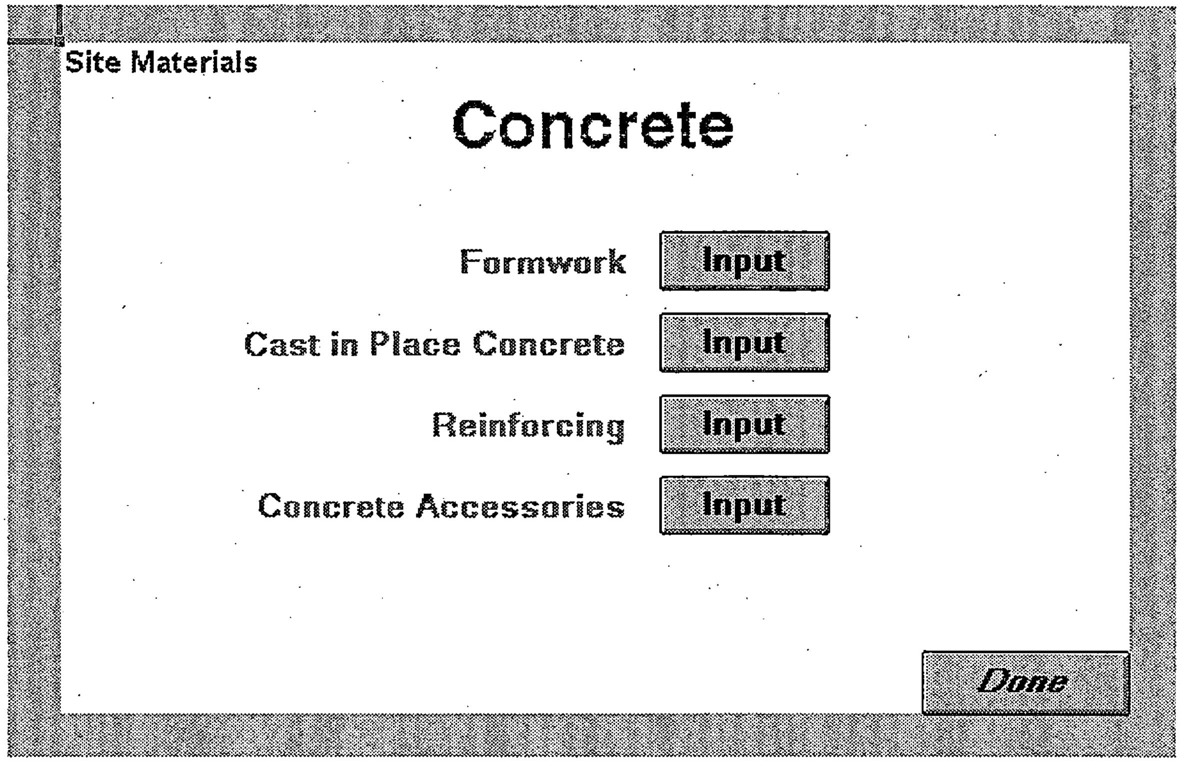

Figure 6. Third level menu screen

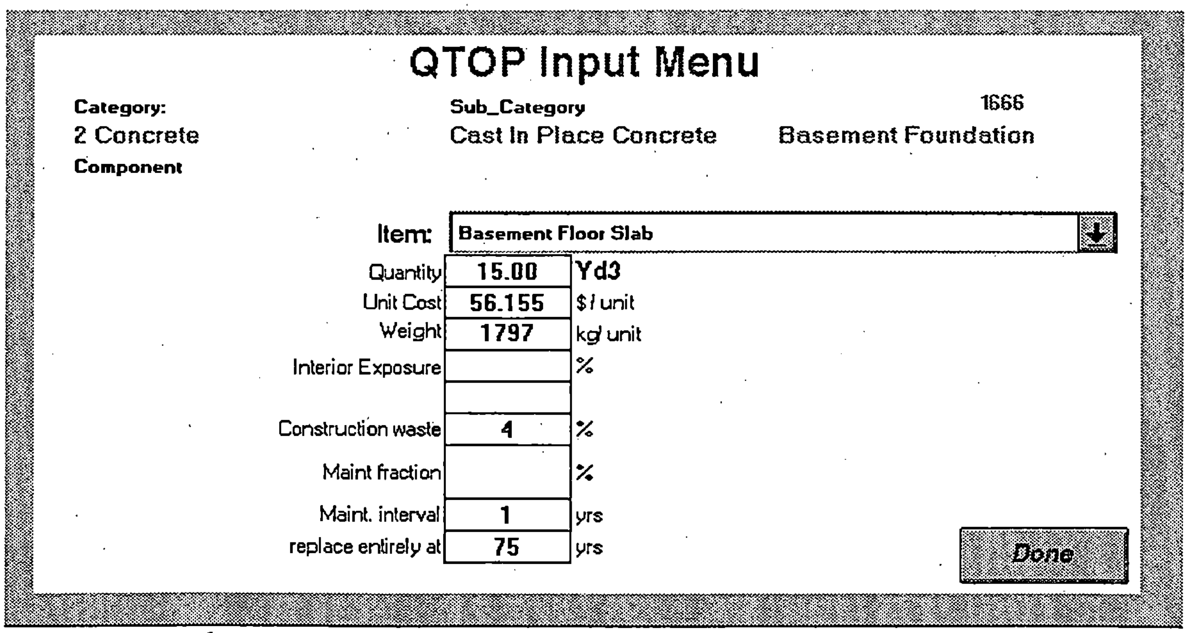

Figure 7. Final Menu Screen for Cast in Place Concrete Floor Slab

A new feature of OPTIMIZE 3.1 is the ability to add new materials to the program. Pressing the New Materials button shown in Figure 5. accesses the

New Materials screen shown in figure 8. From this screen, it is possible to input energy intensity values and feedstock composition of new or custom materials. This feature is especially valuable, for example, when accounting for regional differences in building materials. For example, concrete manufactured in British Columbia uses hydro power and hog fuel as the predominant feedstocks. The default data in OPTIMIZE comes from Statistics Canada information that is based on average production for the entire country. The New Material input screen allows the Statistics Canada data to be altered as appropriate.

After defining the new material, and entering the energy intensity by fuel type, OPTIMIZE automatically creates a new commodity in EMBODY-the worksheet containing the energy intensity database. OPTIMIZE will define the new commodity number. The number will be sequential, following from the commodity chosen as the default. For example, altering cast-in-place concrete (Commodity Number 4200) to create a "B.C. concrete" with new commodity number 4201. Up to nine new commodities can be created for each commodity classification.

Note: *In order for the new material to be used in calculations by OPTIMIZE, the commodity code must be altered for all relevant materials in QTOP. This can be done in various ways:*

I. Edit the numbers in Column O in QTOP, using Excel's Replace utility, for example.

II. Edit the specific materials using the material input screens.

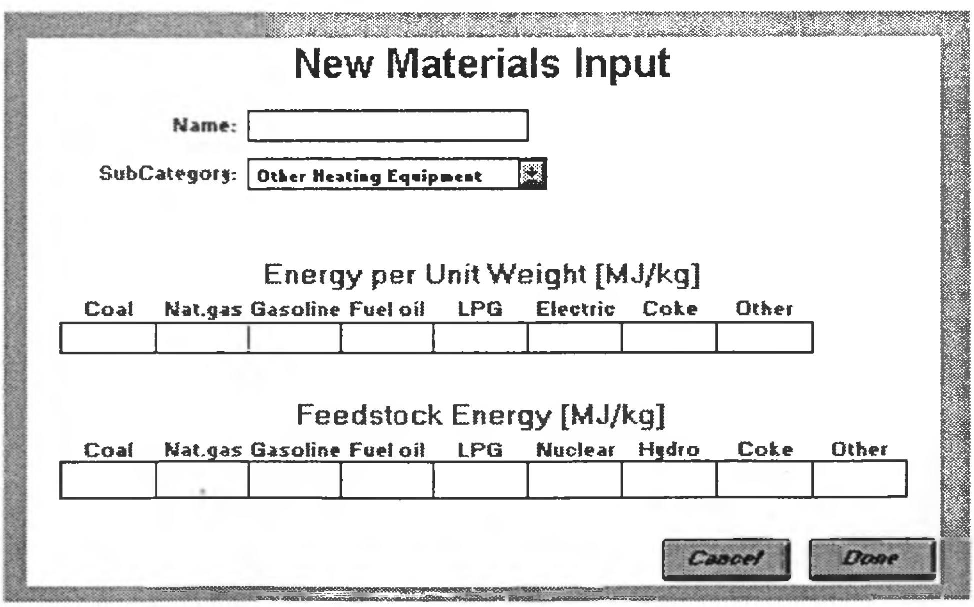

Figure 8. New Materials Input Sheet.

3.3.11 Results

The results button will cause OPTIMIZE 3.1 to recalculate the life-cycle energy and environmental impacts of the building. When the calculations are complete, the Results sub-menu will appear on the screen. The Results sub-menu is shown in Figure 9. From the Results sub-menu the user may view or print the results of the life-cycle calculations. Specific information available from this sub-menu includes:

- life-cycle (operating and embodied) energy of the building;
- initial and life-cycle embodied energy by commodity;
- weight of building by commodity;
- energy related air emissions and their external costs;
- breakdown of indoor air pollutant emission rates;
- life-cycle parameters for the building and its site; and,
- the building costs.

A discussion of these results for a case study building may be found in the next chapter.

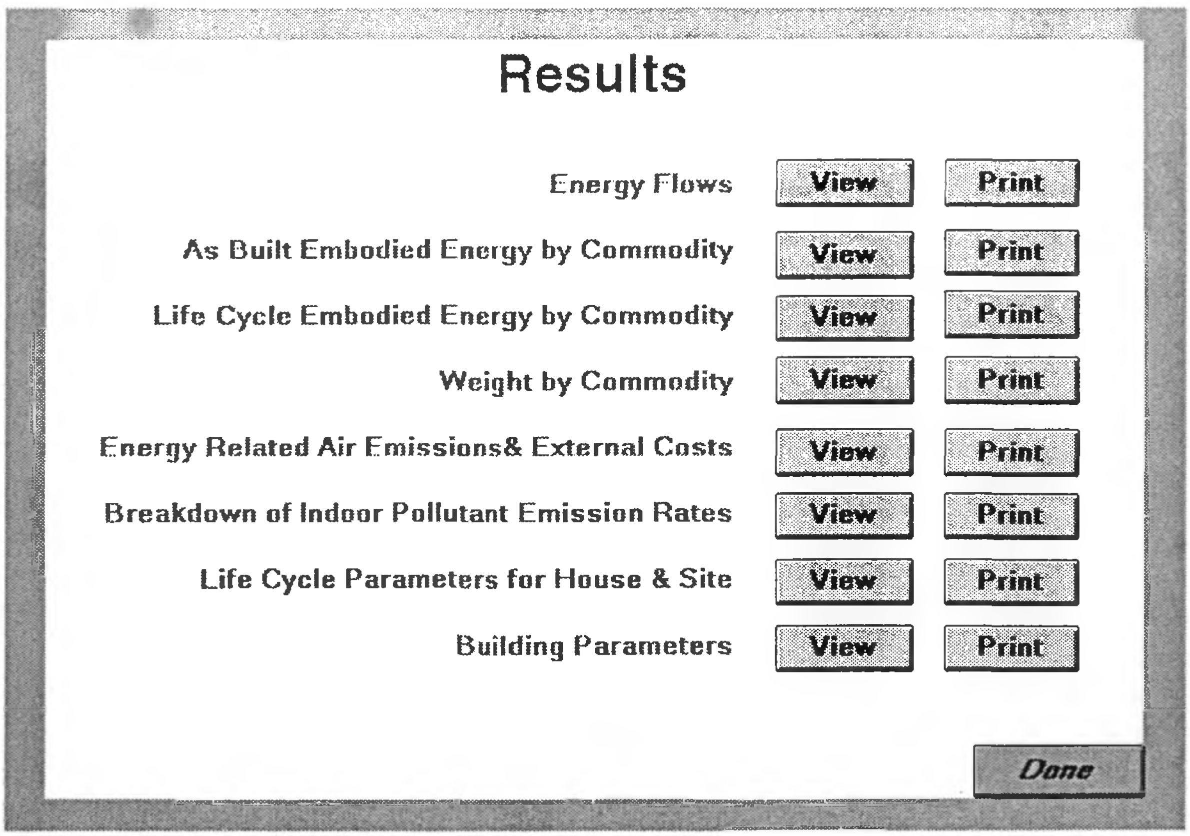

Figure 9. Results Menu

3.3.12 Save

The save button allows the user to save working files. It is also necessary to save a file if it is to be stored in the library of default assemblies.

Chapter Four: Results

4.1 Description of the Standard House

In order to test the OPTIMIZE program and evaluate the results, it was decided to identify a typical detached dwelling and generate some base-line data on embodied energy and environmental impact for Canadian houses. The "Standard Canadian House" is a new, 3 bedroom house with attached double garage, North oriented. This house has an approximate floor area of 350 square meters and a design occupancy of 4 persons. The expected life of the house is taken to be 40 years.

Heated interior space consists of an unfinished basement and two storeys above grade. The basement foundation walls are poured concrete and insulated with 3 1/2" fiberglass batts. Exterior walls in the two storeys above grade are 2x6 framed and insulated with 5 1/2" fibreglass batts. The attic is insulated with 12" blown mineral wool. Interior walls are 2x4 framed.

Interior finish on walls and ceilings throughout is single coat paint plus primer on 1/2" gypsum board. Floor finish is 1/8" vinyl in the kitchen and bathrooms and carpeting elsewhere. Exterior siding consists of a combination of brick veneer and cedar siding. Windows are double glazed. Roofing is asphalt shingles.

Space heating is provided by a natural gas furnace, forced air system with a 30 kW capacity. No central ventilation or cooling system is installed. The hot water heater has a 10 kW capacity. Water supply lines are polybutylene pipe and waste lines are ABS pipe. For this example, the house has been located in Langely, British Columbia.

4.2 Generating Results

Once all the input data has been recorded into OPTIMIZE, clicking the Results button will calculate all output data and switch to the Results Menu. From here, it is possible to view or print the results of the analysis. Sample output from the Standard House file included with the original OPTIMIZE 3.1 disk are included in Appendix 1.

4.3 Results From OPTIMIZE

4.3.1 Energy Analysis

The energy analysis performed by OPTIMIZE for the Standard House predicts the following results:

- The as-built embodied energy is 854 GJ, or 2.4 GJ/sq.m.
- The life-cycle embodied energy is 1763 GJ, or 0.10 GJ/sq.m.yr.
- The total life-cycle energy for the standard house is 0.64 GJ/sq.m.yr.
- The life-cycle embodied energy is approximately 16% of the total life-cycle energy.

The results of the energy analysis are lower than those obtained by Bairn and Aun [1983], or in earlier versions of OPTIMIZE documentation [CMHC, 1991]. This is to be expected, as the results presented here are based on the most recent input-output data available[1].

The top 5 commodities, sorted by weight for the Standard House are presented in Table 1. The estimated weight of the as-built house is 404 000 Kg. Approximately 92% of the weight of the house may be attributed to the five commodities listed below.

TABLE 1. TOP 5 COMMODITIES IN STANDARD HOUSE SORTED BY WEIGHT

Code	Commodity	As-built Total (kg)	Percent of Total
4200	Ready-mix Concrete	224 600	55.6%
470	Sand and Gravel	110 100	27.3%
1970	Lumber & Timber	16 300	4.0%
4260	Gypsum basic Products	10 900	2.7%
4210	Bricks and Tiles, Clay	9700	2.4%
	Estimated Total House Weight	404 000	92%

The As-Built embodied energy for the Standard house is 854 GJ. The top 10 commodities, sorted by initial embodied energy for the Standard House is

[1] There is a downward trend in the energy intensity of goods and services produced in Canada. See Statistics Canada [1993] for details.

presented in Table 2. From the data presented below, approximately 68% of the initial embodied energy of the Standard House may be attributed to the ten materials listed in Table 2.

TABLE 2. TOP 10 COMMODITIES IN STANDARD HOUSE SORTED BY AS-BUILT EMBODIED ENERGY

Code	Commodity	As-built Total (MJ)	Percent of Total
1970	Lumber & Timber*	99 200	11.6%
4190	Ready Mix Concrete	95 000	11.1%
2870	Aluminum Alloys	93 600	11.0%
3330	Plastic Piping and Fittings	74 600	8.74%
2010	Plywood and Veneers	59 600	6.98%
2880	Copper Fabricated Materials	32 300	3.78%
4260	Gypsum Products	32 100	3.76%
2300	Vinyl Floor	30 900	3.62%
5310	Carpet	30 700	3.62%
4350	Mirrors and Glass	28 800	3.37%

*This is not typical of many Canadian houses since it includes one-time use of timber for form work.

The top 10 commodities sorted by life-cycle embodied energy for the standard house is presented in Table 3. The results predict that 62% of the life-cycle embodied energy may be attributed to ten commodity classes.

TABLE 3 TOP 10 COMMODITIES IN STANDARD HOUSE
SORTED BY LIFE-CYCLE EMBODIED ENERGY

Code	Commodity	Life Cycle Total (MJ)	Percent of Total
5310	Carpeting & Fabric Rugs, Mats, Etc.	194 000	13.5%
3330	Plastic Plumbing Fixtures and Fittings	168 500	11.7%
4200	Ready-mix Concrete	146 000	10.2%
1970	Lumber & Timber	143 000	10.0%
2870	Aluminum Alloys	104 900	7.3%
2010	Plywood and Veneers	80 200	5.6%
4260	Gypsum Products	52 400	3.7%
3220	Washers and Dryers	45 000	3.1%
3050	Metal Duct, Siding and Roofing	43 600	3.0%
4570	Paint	38 000	2.6%

4.3.2 Validating the Embodied Energy Results

In order to gain confidence in the calculations performed by OPTIMIZE, an independent method of calculating results may be employed. From the Statistics Canada input-output table, the embodied energy of residential construction is 6.53 MJ/$. From Means [1995], the material cost for construction of an average house is $356/sq.m. Therefore, the total cost of materials for a 350 sq.m house is approximately $124, 500[2]. Multiplying the building material cost by the embodied energy of residential construction predicts an as-built embodied energy of 813 GJ. Based on OPTIMIZE calculations, the as-built embodied energy (including added transportation and construction energy) is 854 GJ. The difference between the two methods of calculation is of the order of 5%.

4.3.3 Environmental Impact of Study House

The major air emissions and their related external costs associated with the study house are summarized in Table 4.

[2] OPTIMIZE predicts a materials cost of $118 000. The difference is of the order of 5%.

Table 4. Air Emissions and External Costs

Emission	Weight [Tonnes]	Externality Cost [$]
CO_2	443	$1319
CO	0.77	N/A
NOX	0.46	$110
SO_2	0.1	$113

The externality costs are based on an assumed discount rate of 10%. In addition, the cost per Kg emissions costs are obtained from the United Nations Intergovernmental Panel on Climate Change [UNPCC, 1992], shown in Table 5.

Table 5. Emission Costs of Common Pollutant

Local Emissions	
Nitrogen Oxides	1.2 $/Kg
Sulfur Oxides	4.9
Total Suspended Particles	2.1
Greenhouse Gases	
Carbon Dioxide	0.015 $/Kg
Methane	0.165

Local emissions have not been adjusted for population size in the OPTIMIZE results. Frequently, the local emissions costs are prorated based on the following weighting factor:

((Population within 100 km of project)*0.9/1million)+0.1

to adjust for population density. Finally, the results of the OPTIMIZE calculations conclude that indoor pollutants which exceed SEIFERT limits are:

- formaldehyde
- benzene
- toluene
- xylene
- undecane
- linonene
- ethylbenzene.

4.4 Discussion of Results

A limitation to all energy analyses, including that performed in OPTIMIZE, is there is no absolutely correct way to define the embodied energy of any good or service. The choice of different system boundaries will result in different predictions for embodied energy. The data in OPTIMIZE uses system boundaries which are consistent with the conventions set out in IFIAS [1974]. Therefore, the value of the current analysis is to identify the relative magnitude among life-cycle components, and to perform comparison studies.

As noted in previous OPTIMIZE documentation, the data used in this program is based on input-output analyses of the Canadian economy. This implies that embodied energy figures used here are averaged over the entire country. The level of disagregation of the input-output tables limits the accuracy of the current analysis in two ways. First, different products are grouped into the same commodity code. Any product whose price is quite different from the average price within the commodity code will result in an inaccurate estimate of embodied energy. Second, the input-output tables are based on national averages. Regional differences in fuel mix or manufacturing process will not show up in a national input-output analysis[3].To increase the accuracy of the program, users may input regionally specific or more current data using the *New Materials* Button in the *Site Materials* Menu.

It is assumed in OPTIMIZE 3.1 that the energy intensity of materials does not change over time. This is a simplification that may result in an overestimate of the life-cycle embodied energy and environmental impacts of the building. In addition, it has been assumed that operating energy does not change over time. It is not clear if the operating energy will increase due to the deterioration of the building, or if it might actually decrease as old, inefficient components are replaced with new, high efficiency systems. The effect of changes to operating energy over time are not clear. More research needs to be performed as this will have a large impact on the life-cycle analysis.

The external costs of pollution predicted by the current version of OPTIMIZE are lower than in the previous versions. Differences may be attributed to the assumption of a non-zero discount rate in all financial calculations. The discount rate for the standard house example is 10%, and may be changed from the Parameters sheet.

The insights from analyzing one standard house is limited. The major task will be to analyze a number of different designs in different locations in the country. The following points are of general interest:

[3] There is process data available which provides region-specific energy intensity values for a number of commodities. See Cole [1993].

- The heaviest materials for the as-built standard house are first concrete, followed by sand and gravel, wood, gypsum, bricks, and plywood.

- The highest embodied energy for the as-built standard house is lumber, followed by concrete, aluminum, plywood, and copper.

- When life-cycle accounting is included, carpets4 are the highest, followed by concrete, lumber, aluminum and plywood.

- The total life cycle energy for the Standard house is 11,337 GJ. The operating energy over the 40-year life-span of the building is 87% of the total, and the embodied energy comprised the remaining 13%.

- The construction energy and demolition energy are almost insignificant at 6 GJ and 4.8 GJ respectively.

- The major externality cost comes from the 440 tonnes of carbon dioxide released into the atmosphere over the life-cycle of the building.

4.5 CONCLUSIONS

OPTIMIZE was successfully used to estimate the embodied energy and environmental impact of a Standard Canadian House. Although the program requires a major time commitment, there is no other way of estimating the embodied energy which is the product of a large number of factors.

The most interesting conclusions to be drawn from OPTIMIZE will come in the future, when a large number of different design options are analyzed. The program is now ready to make a major contribution to the health and sustainability of Canadian housing. As more information of pollution by Canadian manufacturing is compiled and released, OPTIMIZE will become even more powerful in estimating the overall impacts from the choice of building materials.

[4] Based on 5% waste, 20% replacement at 5 year intervals and total replacement at 10 years.

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OPTIMIZE 3.1
Users Manual
Appendix 1: Sample Output for Standard House

November, 1995

Energy Flows

Energy Type

ENERGY BREAKDOWN:

Embodied Energ	Total (GJ)	Coal	Nat.Gas	Gasoline	Fuel Oil (GJ)	LPG	Nuclear	Hydro	Coke	Other
Materials Acquisition	817									
Construction	6									
Added Transport	31									
Maint. & Replace.	832									
Disposal/Recovery	67									
Total Embodied	1,763	273	652	132	269	67	104	201	53	10
Total Operating	9,486		7,395		406			1,685		
TOTAL Life-Cycle Energy	11,249	273	8,047	132	269	67	104	1,886	53	10

	Total	Coal	Nat.gas	Gasoline	Fuel oil	LPG	Nuclear	Hydro	Coke	Other
Operating Energy (GJ/yr)	190		148		8			34		

Maint. & Replacement Energy Flow	Total	Coal	Nat.gas	Gasoline	Fuel oil	LPG	Nuclear	Hydro	Coke	Other
Site (assumed electrical)	0.137	0.044	0.002		0.005		0.029	0.055		0.001
Embodied [MJ]	774,252	130,642	354,360	19,784	84,664	27,967	45,266	85,836	21,053	4,681
Totals:	774,253	130,643	354,360	19,784	84,664	27,967	45,266	85,836	21,053	4,681

Construction Energy split(MJ):

	Total	Coal	Nat.gas	Gasoline	Fuel oil	LPG	Nuclear	Hydro	Coke	Other
Totals:	6,000		480		120			5,400		
	100%		*8%*		*2%*			*90%*		

Demolition Energy split(MJ):

	Total	Fuel oil
Totals:	4,800	4,800
		100%

	Coal	Nat.gas	Gasoline	Fuel oil	LPG	Nuclear	Hydro	Coke
Energy Content of Fuels:	27.35 MJ/kg	37.82 MJ/m^3	34.66 MJ/L	41.73 MJ/L	25.53 MJ/L	3.6 MJ/kWh	3.6 MJ/kWh	28.83 MJ/kg

Energy Assumptions

Electrical Energy Generation Factors:

	Coal	Nat.gas	Gasoline	Fuel oil	LPG	Nuclear	Hydro	Coke	Other	
Dist. National:	18.4%	1.0%		2.1%		11.6%	66.7%		0.3%	Distribution
Dist: Prov		8.0%		2.0%			90.0%			Dist: Prov
Efficiency:	29.7%	33.0%	28.5%	28.5%	33.0%	28.7%	87.0%	29.7%	28.7%	Efficiency
Elect.Mult.:	0.618	0.030		0.073		0.404	0.766		0.011	Elect.Mult.
Regn. Mult:		0.24242424		0.07017544			1.03448276			Regn. Mult:

AsBuilt Embodied Energy by Commodity

Commodity	As built (kg)	Total (MJ)	Coal	Nat.gas	Gasoline	MJ Fuel oil	LPG	Nuclear	Hydro	Coke	Other
Sand (Excl Silica) & Gravel	110,139	4,922	927	674	311	1,821	219	305	578	62	25
Plastic Film & Sheet	113	8,165	1,213	4,715	142	544	212	436	826	34	44
Foamed & Expanded Plastics	30	2,381	308	1,465	38	171	61	109	208	10	12
Plastic Building Supplies	324	18,707	2,601	11,396	301	1,086	422	919	1,742	147	94
Lumber	16,341	99,207	18,522	16,088	6,469	34,067	3,053	6,791	12,877	644	697
Treated Lumber & Wood Products	6,114	38,540	8,515	8,851	2,434	9,609	1,280	2,503	4,747	272	326
Plywood & Veneer	4,443	49,596	8,305	17,916	2,169	11,152	1,456	2,771	5,255	275	299
Millwork	2,421	15,833	3,198	3,994	1,129	3,370	534	1,098	2,083	258	170
Building Board & Paper	19	145	22	36	2	20	36	9	17	3	0
Asphalt Building Products	2,524	8,239	455	1,475	60	547	4,794	162	307	424	16
Vinyl Floor & Wall Covering	1,027	30,942	1,761	25,961	229	845	258	616	1,168	40	63
Reinforcing Bars & Rods	31	888	128	201	10	69	88	50	94	246	3
Tar & Pitch	2,089	2,920	431	964	51	262	238	169	321	469	15
Other Iron & Steel Pipes & Tubes	234	8,926	1,367	2,340	130	770	760	520	986	2,015	38
Other Cast Iron Products	24	772	91	155	7	28	7	32	60	389	2
Aluminum & Alum.Alloy Fabricated Mat.	963	93,581		36,359	1,533	10,706	1,694	14,250	27,022	1,313	704
Copper Fabricated Materials	298	32,256	9,107	6,659	486	2,743	406	4,076	7,729	862	187
Zinc & Zinc Alloy Fabricated Mat.	8	110	24	39	2	10	2	11	20	1	1
Fabricated Steel Plate	73	4,240	687	1,125	111	405	332	261	494	797	28
Other Metal Building Products	16	983	165	296	29	91	64	63	119	148	7
Iron & Steel Stampings	13	381		154	9	38	29	25	47	76	2
Metal Roofing, Siding, Ducts, Etc	769	28,556		11,000	779	3,007	2,205	2,058	3,902	5,410	195
Other Metal Containers & Closures	14	667	105	230	13	62	41	40	75	98	3
Fastener Hardware	218	8,416	1,417	2,847	178	674	502	523	991	1,239	46
Builders' Hardware	37	1,273	252	359	48	119	59	91	173	160	11
Household Clothes Washers & Dryers, D	195	8,549	1,547	3,021	258	778	528	560	1,063	718	77
Other Heating Equipment	0	4	1	1	0	0	0	0	1	0	0
Non-Elect. Furnaces & Heat Equip	80	2,944	508	968	101	273	174	187	354	356	25
Oil & Gas Burners, Etc	85	3,476	611	1,124	129	330	201	224	424	402	31
Plastic Plumbing Fixtures & Fittings	865	74,605	15,983	29,734	1,926	6,981	2,432	5,622	10,660	692	574
Fans & Air Circ. Units, Not Indust.	10	652	121	203	22	57	29	45	86	82	6
Small Hhold Appliances, Incl Microwave	86	4,283	741	1,495	234	411	212	267	507	364	52
Household Refrigerators & Freezers	80	3,182	567	1,114	101	291	202	206	390	282	29
Hhold Cooking Equip, Excl Microwave	60	759	134	263	27	70	47	49	92	69	7
Electronic Alarm & Signal Systems	2	45	11	11	3	6	1	4	7	1	1
Wire & Cable, Insulated, Excl Alum.	105	3,410	918	830	51	301	57	413	783	34	23
Wiring Materials & Electrical Meters	125	2,165	477	707	72	193	74	174	330	116	22
Cement	2,223	15,958	7,090	4,017	77	1,085	65	682	1,294	1,616	31
Concrete Products, Incl Sand & Lime	2,028	1,323	370	445	33	181	37	60	113	78	6
Ready-Mix Concrete	224,625	94,985	29,332	26,681	1,913	18,317	1,534	3,788	7,184	5,869	366
Bricks & Other Clay Building Products	9,715	15,910	1,556	11,477	142	1,023	131	519	984	40	39
Natural Stone Products	10	2	0	1	0	0	0	0	0	0	0
Gypsum Building Products	10,945	32,141	5,995	15,542	458	3,577	549	2,005	3,802	69	144
Mineral Wool Building Products	2,112	17,132	3,991	7,304	302	1,265	261	1,337	2,535	39	97
Mirrors & Glass Household Products	1,067	28,819	4,278	17,084	476	2,028	428	1,466	2,781	152	125
Paints & Related Products	509	10,098	2,011	3,767	303	1,036	503	791	1,499	102	86
Pigments & Dyes	5	292	69	99	5	20	9	30	57	1	1
Synthetic Rubber	0	30	2	25	0	1	1	1	1	0	0
Adhesives	116	4,928	785	2,295	135	544	225	297	562	48	37
Floor & Wall Covering, Excl. Vinyl	407	30,729	5,881	13,941	794	2,785	846	2,106	3,994	162	220

Life Cycle Embodied Energy by Commodity

Commodity	Total	Coal	Nat.gas	Gasoline	MJ Fuel oil	LPG	Nuclear	Hydro	Coke	Other
Sand (Excl Silica) & Gravel	7,202	1,357	987	454	2,665	320	446	846	91	37
Plastic Film & Sheet	9,233	1,371	5,332	160	615	239	492	934	39	49
Foamed & Expanded Plastics	2,555	330	1,572	41	183	65	117	223	10	13
Plastic Building Supplies	27,992	3,892	17,052	450	1,626	631	1,375	2,607	220	140
Lumber	143,784	26,844	23,316	9,375	49,375	4,424	9,842	18,663	933	1,011
Treated Lumber & Wood Products	40,568	8,963	9,317	2,563	10,115	1,347	2,635	4,997	287	343
Plywood & Veneer	80,249	13,437	28,988	3,509	18,044	2,355	4,484	8,503	445	483
Millwork	26,256	5,302	6,622	1,872	5,588	886	1,821	3,454	428	282
Building Board & Paper	234	35	58	2	32	58	15	28	5	1
Asphalt Building Products	18,031	996	3,227	131	1,197	10,492	355	673	927	34
Vinyl Floor & Wall Covering	169,365	9,642	142,100	1,252	4,626	1,414	3,371	6,392	220	348
Reinforcing Bars & Rods	935	135	212	10	73	92	52	99	258	3
Tar & Pitch	3,842	567	1,268	67	345	313	223	423	617	20
Other Iron & Steel Pipes & Tubes	15,782	2,418	4,138	230	1,362	1,344	919	1,743	3,563	67
Other Cast Iron Products	1,262	149	253	12	47	11	52	99	636	3
Aluminum & Alum.Alloy Fabricated Mat.	104,894		40,754	1,719	12,001	1,899	15,973	30,288	1,471	790
Copper Fabricated Materials	34,120	9,634	7,044	514	2,902	429	4,311	8,176	912	198
Zinc & Zinc Alloy Fabricated Mat.	115	26	41	2	10	2	11	21	2	1
Fabricated Steel Plate	5,356	868	1,422	140	511	419	329	624	1,007	36
Other Metal Building Products	1,034	174	312	31	96	68	66	125	156	8
Iron & Steel Stampings	509		207	11	51	39	33	63	102	3
Metal Roofing, Siding, Ducts, Etc	43,646		16,813	1,190	4,596	3,370	3,145	5,964	8,269	298
Other Metal Containers & Closures	702	111	242	14	65	43	42	79	104	4
Fastener Hardware	10,107	1,702	3,418	213	810	603	628	1,190	1,488	55
Builders' Hardware	1,340	266	378	50	125	62	96	183	168	12
Household Clothes Washers & Dryers, D	44,995	8,140	15,902	1,357	4,093	2,779	2,949	5,593	3,776	405
Other Heating Equipment	12	2	4	0	1	1	1	2	1	0
Non-Elect. Furnaces & Heat Equip	10,304	1,777	3,386	355	954	607	653	1,238	1,246	89
Oil & Gas Burners, Etc	13,904	2,446	4,497	516	1,319	804	894	1,696	1,610	124
Plastic Plumbing Fixtures & Fittings	168,466	36,092	67,143	4,350	15,763	5,491	12,695	24,072	1,563	1,297
Fans & Air Circ. Units, Not Indust.	2,150	400	671	73	188	96	149	283	269	21
Small Hhold Appliances, Incl Microwave	14,959	2,588	5,221	817	1,435	741	934	1,771	1,270	181
Household Refrigerators & Freezers	16,746	2,983	5,866	533	1,532	1,065	1,082	2,052	1,482	152
Wire & Cable, Insulated, Excl Alum.	12,564	3,381	3,057	189	1,110	210	1,521	2,885	126	85
Wiring Materials & Electrical Meters	6,447	1,421	2,105	214	576	221	518	982	344	65
Cement	22,678	10,075	5,709	110	1,542	92	970	1,839	2,297	45
Concrete Products, Incl Sand & Lime	1,691	473	568	42	232	47	76	144	100	8
Ready-Mix Concrete	146,435	45,221	41,133	2,949	28,239	2,364	5,840	11,075	9,048	565
Bricks & Other Clay Building Products	23,038	2,253	16,618	206	1,482	189	751	1,424	58	57
Natural Stone Products	5	1	2	0	1	0	0	1	0	0
Gypsum Building Products	52,356	9,766	25,317	746	5,827	894	3,266	6,194	113	234
Mineral Wool Building Products	25,153	5,860	10,724	443	1,857	384	1,963	3,722	57	142
Asbestos Products										
Other Non-Met. Mineral Basic Prod.										
Optical Fibre Cables										
Glass Fibre Batts, Mats, Etc.										
Mirrors & Glass Household Products	36,994	5,492	21,930	611	2,604	550	1,882	3,570	196	160
Paints & Related Products	38,620	7,692	14,405	1,157	3,964	1,924	3,024	5,733	391	330
Pigments & Dyes	584	137	198	11	40	19	60	113	3	3
Synthetic Rubber	88	4	72	0	2	3	2	3	0	0
Adhesives	6,048	963	2,817	166	667	276	364	690	59	46
Floor & Wall Covering, Excl. Vinyl	194,080	37,145	88,049	5,016	17,589	5,341	13,302	25,225	1,024	1,389

Weight Breakdown by Commodity

Code	Commodity	As-Built (kg)	Life Weight (kg)
470	Sand (Excl Silica) & Gravel	110,139	161,172
1420	Plastic Film & Sheet	113	128
1430	Foamed & Expanded Plastics	30	32
1450	Plastic Building Supplies	324	484
1970	Lumber	16,341	23,684
1980	Treated Lumber & Wood Products	6,114	6,436
2010	Plywood & Veneer	4,443	7,188
2040	Millwork	2,421	4,015
2250	Building Board & Paper	19	31
2260	Asphalt Building Products	2,524	5,524
2300	Vinyl Floor & Wall Covering	1,027	5,622
2600	Reinforcing Bars & Rods	31	32
2660	Tar & Pitch	2,089	2,749
2700	Other Iron & Steel Pipes & Tubes	234	414
2710	Other Cast Iron Products	24	40
2870	Aluminum & Alum.Alloy Fabricated Mat.	963	1,080
2880	Copper Fabricated Materials	298	315
2920	Zinc & Zinc Alloy Fabricated Mat.	8	8
2940	Fabricated Steel Plate	73	92
3010	Other Metal Building Products	16	17
3040	Iron & Steel Stampings	13	17
3050	Metal Roofing, Siding, Ducts, Etc	769	1,175
3080	Other Metal Containers & Closures	14	15
3150	Fastener Hardware	218	262
3160	Builders' Hardware	37	39
3220	Household Clothes Washers & Dryers, Dishw	195	1,026
3260	Non-Elect. Furnaces & Heat Equip	80	280
3270	Oil & Gas Burners, Etc	85	340
3330	Plastic Plumbing Fixtures & Fittings	865	1,954
3450	Fans & Air Circ. Units, Not Indust.	10	33
3910	Small Hhold Appliances, Incl Microwave	86	301
3930	Household Refrigerators & Freezers	80	421
3940	Hhold Cooking Equip, Excl Microwave	60	300
4030	Electronic Alarm & Signal Systems	2	4
4110	Wire & Cable, Insulated, Excl Alum.	105	386
4130	Wiring Materials & Electrical Meters	125	373
4170	Cement	2,223	3,158
4190	Concrete Products, Incl Sand & Lime	2,028	2,591
4200	Ready-Mix Concrete	224,625	346,297
4210	Bricks & Other Clay Building Products	9,715	14,067
4250	Natural Stone Products	10	20
4260	Gypsum Building Products	10,945	17,829
4270	Mineral Wool Building Products	2,112	3,101
4350	Mirrors & Glass Household Products	1,067	1,370
4570	Paints & Related Products	509	1,948
4980	Pigments & Dyes	5	9
5000	Synthetic Rubber	0	1
5080	Adhesives	116	142
5310	Floor & Wall Covering, Excl. Vinyl	407	2,570

Breakdown of Air Emissions and External Costs

Default Nominal Emission Rates (mg/MJ)

Pollutant	Total	Coal	Nat.gas	Gasoline	Fuel oil	LPG	Nuclear	Hydro	Coke	Other
Carbon Dioxide	421,600	85,000	49,700	68,000	73,100	59,800			86,000	
Particulates	385	65	1	100	154	1			64	
Nitrogen Oxides	1,025	250	42	390	60	43			240	
Sulfur Dioxide	774	330	0	12	102	0			330	
VOCs	636	2	1	630	1	1			1	
Methane	74	1	1	70	0	1			1	
Carbon Monoxide	5,580	93	9	5,365	16	10			88	
Arsenic	.3	.29			.01					
Beryllium	.04	.04								
Cadmium	.03	.02			.01					
Chromium	.62	.61			.01					
Copper	.49	.37			.12					
Mercury	.02	.01			.01					
Manganese	1.29	1.28			.01					
Nickel	1.04	.5			.54					
Lead	.15	.14			.01					
Formaldehyde	.23	.06			.17					
other	.17					.17				
CFC	128					128				

Accumulated Energy Related Emissions by Fuel Source

	Total	Coal	Nat.gas	Gasoline	Fuel oil	LPG	Nuclear	Hydro	Coke	Other
Carbon Dioxide	451,962	20,225	396,676	8,678	18,523	3,657			4,204	
Particulates	81	15	10	13	39	0			3	
Nitrogen Oxides	474	59	335	50	15	3			12	
Sulfur Dioxide	124	79	2	1	26	0			16	
VOCs	91	0	10	80	0	0			0	
Methane	20	0	10	9	0	0			0	
Carbon Monoxide	783	22	68	685	4	1			4	
Arsenic	72	70			2					
Beryllium	9	8			0					
Cadmium	6	5			2					
Chromium	146	144			2					
Copper	117	87			30					
Mercury	5	2			4					
Manganese	307	305			3					
Nickel	256	119			137					
Lead	35	32			3					
Formaldehyde	57	13			44					

Outdoor Emissions		Externality Cost*
Carbon Dioxide	451,962 kg	$1,344
Particulates	81 kg	$34
Nitrogen Oxides	474 kg	$113
Sulfur Dioxide	124 kg	$120
VOCs	91 kg	not avail.
Methane	20 kg	$3
Carbon Monoxide	783 kg	not avail.
Arsenic	72 g	not avail.
Beryllium	9 g	not avail.
Cadmium	6 g	not avail.
Chromium	146 g	not avail.
Copper	117 g	not avail.
Mercury	5 g	not avail.
Manganese	307 g	not avail.
Nickel	256 g	not avail.
Lead	35 g	not avail.
Formaldehyde	57 g	not avail.
		not avail.
Nuclear		$82
Hydro		$147
	TOTAL:	$1,843

discount rate= 10%

Breakdown of Indoor Air Pollutants

Emission Rates by Source

Emission Rates / Hazard / Limit (ug/m^3)	Aldehyde	Indoor Pollutants	Aromatic		Alkane		Terpene		Ether
	Formaldehyde S/Carcinogen	Benzene S/Carcinogen	Toluene Carcinogen	Xylene Irritant	Nonane Irritant	Undecane Irritant	Limonene Irritant	A-pinene Irritant	Ethylebenzene Irritant
Source	(ug/m^2hr)	(ug/m^2hr)	(ug/m^2hr)	(ug/m^2hr)	(ug/m^2hr)	(ug/m^2hr)	(ug/m^2hr)	(ug/m^2hr)	(ug/m^2hr)
Vinyl flooring	30								40
Carpet	10		60	0		12			
Wallcovering, wallpaper	15		50		10	18			
Paint		7	150				50		
Adhesive							190		
Caulking		5	20	41					2
OSB, particle board	300				10			25	
Plywood	20								
Gyproc				6		90			

Total Emissions by Source

Emissions: Source	Source Equivalent (m^2)	Formaldehyde (ug/hr)	Benzene (ug/hr)	Toluene (ug/hr)	Xylene (ug/hr)	Nonane (ug/hr)	Undecane (ug/hr)	Limonene (ug/hr)	A-pinene (ug/hr)	Ethylebenzene (ug/hr)
Vinyl flooring	150	4,499								5,998
Carpet	162	1,623		9,741	67		1,948			
Wallcovering, wallpaper										
Paint	1,045		7,525	156,763				52,254		
Adhesive	168							32,009		
Caulking	9		47	181	372					18
OSB, particle b										
Plywood	202	4,046								
Gyproc	1,046				6,693		94,119			
other...										
other...										
	Sum:	10,169	7,572	166,685	7,131		96,067	84,263		6,016

	Indoor Emissions (ug/hr)	Concentration** Actual (ug/m3)	Limit*** (ug/m3)	
Formaldehyde	10,169	27		over limit
Benzene	7,572	20		over limit
Toluene	166,685	443		over limit
Xylene	7,131	19		over limit
Nonane				
Undecane	96,067	255		over limit
Limonene	84,263	224		over limit
A-Pinene				
Ethylbenzene	6,016	16		over limit

** Indoor concentrations based on emissions from a subset of new materials (constant air change rate).
***Limits to indoor concentrations are from Seifert

Building Parameters

Lifespan (years)	50
Discount Rate (%)	10%

Construction/Demolition Default Inputs

Site Prep.: % Removed	50%	
Distance	30	km (truck)
Construction Materials added haulage:		
Truck	20	km
Train	0	km
Ship	0	km
Air	0	km
Construction: Energy	6,000	MJ (mixed)
Trades transport.	6,000	person.km
Waste: Hauled	30	km (truck)
Demolition Energy	4,800	MJ (mixed)

Maintenance/Replacement Default Inputs

Energy	20	kWh/year
Distance	30	km (van)

MAINTENANCE/REPLACEMENT:

ENVIRONMENTAL FACTORS:

	Outdoor Emissions		**Externality Cost**
Carbon Dioxide	451,962	kg	$1,344
Particulates	81	kg	$34
Nitrogen Oxides	474	kg	$113
Sulfur Dioxide	124	kg	$120
VOCs	91	kg	not avail.
Methane	20	kg	$3
Carbon Monoxide	783	kg	not avail.
Arsenic	72	g	not avail.
Beryllium	9	g	not avail.
Cadmium	6	g	not avail.
Chromium	146	g	not avail.
Copper	117	g	not avail.
Mercury	5	g	not avail.
Manganese	307	g	not avail.
Nickel	256	g	not avail.
Lead	35	g	not avail.
Formaldehyde	57	g	not avail.
CFCs		g	not avail.
Nuclear			$82
Hydro			$147
		TOTAL:	$1,843

discount rate= 10%

COSTS:	**Materials -**		**$**
	House as built		$120,002
	Maintenance, Replacement & Waste		$21,457
		Total Materials	$141,460
	Operating Energy Costs		
	Externality Costs		$1,843
		TOTAL COST*	$143,302
		Cost per person housed	$35,826

* Note that costs do NOT include charges for externality costs for which data is unavailable