DEMOLITION ENERGY ANALYSIS OF OFFICE BUILDING STRUCTURAL SYSTEMS

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Preface

This report was commissioned as part of the continuing program to expand the knowledge base of the ATHENA™ project. The project was initiated in 1990 by Forintek Canada Corp., with the support of Natural Resources Canada, under the name Building Materials in the Context of Sustainable Development. Work on the ATHENA™ project is now being carried forward by the ATHENA™ Sustainable Materials Institute, a not-for-profit organization dedicated to helping the building community meet the environmental challenges of the future.

The ultimate goal is to foster sustainable development by encouraging selection of the material mix that will minimize a building’s life cycle environmental impact. To achieve that goal the Institute is developing ATHENA™, a systems model for assessing the relative life cycle environmental implications of alternative building or assembly designs. Intended for use by building designers, researchers and policy analysts, ATHENA™ is a decision support tool which compliments and augments other decision support tools like costing models. It provides a wealth of information to help users understand the environmental implications of different material mixes or other design changes in all or part of a building.

The ATHENA™ Institute is continuing the practice of publishing all individual research reports and major progress reports to make the process as transparent as possible and to ensure the research and results are fully accessible. To ensure continuity, previously published reports are being reissued as part of the Institute series.

Institute studies and publications fall into two general categories: investigative or exploratory studies intended to further general understanding of life cycle assessment as it applies to building materials and buildings; and individual life cycle inventory studies which deal with specific industries, product groups or building life cycles stages. All studies in this latter category are firmly grounded on the principles and practices of life cycle assessment (LCA), and follow our published Research Guidelines which define boundary or scope conditions and ensure equal treatment of all building materials and products in terms of assumptions, research decisions, estimating methods and other aspects of the work. The integration of all inventory data is a primary function of ATHENA™ itself. ATHENA™ also generates various composite measures that can be best described as environmental impact indicators, a step toward the ultimate LCA goal of developing true measures of impacts on human and ecosystem health.

We believe this report and others in the series will be of value to people concerned with the environmental implications and sustainability of our built environment. But we caution that individual industry life cycle study reports may not be entirely stand-alone documents in the sense that they tell the whole story about an individual set of products. For example, the report on concrete notes how much steel is used for reinforcing various products, but the life cycle inventory data for those steel products is included in the reports dealing with integrated and mini-mill steel production. There are also transportation and energy production and distribution aspects that are common to many different building products and are therefore handled separately within ATHENA™.

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1.0 INTRODUCTION

The life cycle energy of a building is comprised of the energy required to initially construct the building, the recurring energy required for periodic refurbishment and maintenance, the energy required for operation during its life, and finally the energy required to demolish and dispose of the building at the end of its lifespan. This study examines the last of these life cycle phases, demolition, and reviews other activities which potentially impact demolition energy.

A previously defined, generic office building was analyzed using a case study format to determine, in absolute terms, the energy required for demolition of the structural system. Three different structural assembly types; wood, steel, and concrete, were analyzed by applying a baseline demolition methodology and then calculating the required energy to effect demolition. The results of the analysis provide a relative indication of the significance of demolition energy and will be used to determine how demolition energy will be incorporated into ATHENA™.

1.1 BACKGROUND

Construction has undergone a remarkable transformation as society has developed and embraced science and technology as a fundamental component of virtually all areas of endeavour. What was once a direct response to the most basic of human needs - protection and shelter from the elements - has become one of the most energy and resource intensive of all of mankind's activities. The seemingly simple task of providing shelter has grown into a pervasive phenomena sometimes termed the "built environment", which now consumes 40% of the planetary material and energy production, 17% of the fresh water consumption, and 25% of the annual global wood harvest.¹

The evolution of buildings from basic utilitarian structures into icons which can be considered the ultimate expression of human control over the natural environment, has resulted in a profound shift in resource consumption patterns. Historically, humankind learned to build before learning to compute and draw, and as a result ancient structures utilized materials of local origin which did not undergo significant alteration to either
form or substance. With the advent of industrialization, the resource trail of construction materials increased dramatically as did the energy embodied within them. Construction materials become specific to their application as engineering principles tied requirement analysis to material production.

The trend of using engineered materials was coupled with the development of high capacity production and transportation systems which were underwritten by the availability of cheap, non renewable energy resources (mainly hydrocarbons). This practice has resulted in the prevalence of specialized, non-adaptable buildings and structures. From a production and maintenance standpoint, this translates into extremely high initial embodied and recurring energies, with the requisite toll on all elements of the natural environment. From a disposal perspective, it is manifest as vast quantities of high entropy construction and demolition (C&D) waste which is at present, difficult to recycle and often impossible to reuse.

The evolution of construction waste management has progressed from a circular resource flow regime to one of a linear nature. Historically, recycling and reuse of building materials and residual products from the construction process itself was a common, if not standard practice. Many buildings in the old city of Cairo incorporate limestone face brick removed from the nearby pyramids, St. Albans Abbey in southern England was constructed 900 years ago using bricks salvaged from Roman ruins which are 1000 years older, and until the advent of mechanized demolition in the 1950’s, deconstruction and reuse of buildings and components was commonplace.

The establishment of a linear resource trail is characterized by a disconnection between the generation of waste materials and their ultimate disposition. Waste products are the remnants of energy and resource consumption and represent conversion from higher states of order (low entropy) to lower, more disordered conditions (high entropy). In a linear system the waste products are of such high entropy that they are difficult to cycle back into the original system for use in other processes without the application of large quantities of additional energy. This is precisely the situation which exists in the C&D waste context. Typical C&D waste streams are disordered, contaminated, and physically altered to the point where energy efficient reuse (or cycling back into the system) is difficult. This is the diametric opposite of circular natural ecosystems where virtually all waste products are utilized as feedstock for other processes. This disparity defines, in a fundamental way, the difference between sustainable and unsustainable systems.

Unfortunately, the demise of the recycling and reuse ethic is symptomatic of a global progression towards unsustainable resource consumption. Mankind’s obsession with technology and exploitation of non renewable energy reserves has resulted in the
normalization of a "faster + cheaper = better " mindset. Little regard to the long term ramifications of actions based on economic rather than ecological considerations is given in our frenetic, growth based society. On a macro scale, this results in a current appropriated carrying capacity (an equivalence measure of the land area required to support all of a given population's resource, waste disposal, and energy needs) of three times the surface area of the planet.¹

On a more industry specific level, the foregoing is represented by heavy infusions of energy and mechanized processes in all phases of construction including demolition. Structures are built under extremely compressed schedules, and with non standardized components and systems. Adverse weather and site conditions are overcome by the application of energy and technology, and materials are procured on a time and cost consideration only. Typical Industrial Institutional and Commercial (ICI) buildings employ global procurement and disposal trails and are not designed or constructed with the intention of deconstructing and reusing the components which were obtained at such an extreme environmental cost.

Given the above, it is not surprising that C&D waste can comprise up to 41% of a typical urban waste stream, and yet only 42% of the total quantity generated is typically diverted from landfills.³ This situation is somewhat discouraging when one considers that, unlike many industries, virtually all C&D waste can be easily reused or recycled using current technology.

Although current practices are not particularly focused toward a circular C&D waste management philosophy, there is reason to maintain some optimism for the future. The C&D recycling and reuse industry is expanding and it is an axiom that the 3Rs will be an integral part of construction by the end of most new buildings' life cycles. Demolition of the future will be predicated by the availability and cost of new resources and by the scarcity of hydrocarbons available for machine operation, as well as by heightened environmental awareness. Unfortunately, many of the powerful drivers for this process are often negative in origin. As an example, waste reduction legislation and escalating landfill tipping fees are the direct result of diminishing landfill capacity and the difficulty of siting new landfill facilities.

Although the foregoing examples are somewhat oversimplified (multiple technical, social, institutional, and cultural factors are also involved), it is a truism that both the demolition industry and governments will eventually be forced by necessity to reuse and recycle. It is interesting to note that reuse and recycling were first employed due to a lack of technological capability to easily access resources and fabricate new building components. Ironically, reuse and recycling practices will ultimately be re-employed because too much technology and resource exploitation has greatly
diminished energy and material reserves.\textsuperscript{7}

Whatever the origin of the impetus, the application of 3R principles to building demolition (as well as to construction) must be performed in a holistic fashion with a rigorous examination, and preferably quantification, of the variables involved. The ATHENA\textsuperscript{TM} project is an example of a comprehensive, holistic model and it is the framework under which this study was performed.

1.2 OBJECTIVES

1.2.1 Context and Relation to Previous Studies

Previous ATHENA\textsuperscript{TM} studies have developed energy intensities as well as other environmental inputs and outputs for various structural materials (wood, concrete and steel). Related case studies of a generic office building have included the embodied energy for material production, building construction, as well as recurring energy. A previous ATHENA\textsuperscript{TM} report entitled \textit{Life Cycle Energy Use in Office Buildings}, identified demolition energy as a component of the total life cycle energy, but did not perform a detailed analysis of the subject. This was due to uncertainties in the waste management practices anticipated in the future, and due to the comparatively small magnitude of demolition energy relative to overall embodied energy.\textsuperscript{8}

While the focus of the ATHENA\textsuperscript{TM} model is on the relative environmental implication of alternative designs, the model also provides an absolute quantitative analysis of life cycle energy. It was therefore decided to examine the demolition process and the corresponding energy expenditures in greater detail. To meet that objective, this study undertakes a general review of the demolition process and its ancillary influences, and analyzes the demolition energy for a specific case (the structural elements of a 4620 m\textsuperscript{2} building) for incorporation into ATHENA\textsuperscript{TM}. The analysis performed herein is specific to the case studies described by the previous ATHENA\textsuperscript{TM} report, \textit{Life Cycle Energy Use in Office Buildings}, and likewise the baseline methodology and time/material take offs are specific to the engineered drawings and specifications developed for that report.\textsuperscript{9}

Determination of the demolition energy also allows analysis of competing demolition strategies to gain insight into their relative merits from an energy expense standpoint. The rationale for this type of comparison can be described as follows:

"Resources should (sic) be redirected at a rate of total resource, money, and energy expenditure which is less than that of providing or creating new or comparable resources, thus showing that such salvaged material results from economic and energy
expenditures that are net gains, or averted losses.

This study will partially enable the above analysis to be performed, since the specific energies associated with differing demolition processes will be determined for comparative structural assemblies.

1.2.2 Areas of Focus

The following five questions will be addressed in this report:

1. How is demolition (for recycling) and deconstruction (for reuse) performed now and how will it change in the future?

2. What techniques would be used to demolish and deconstruct (respectively) structural frames composed of wood, steel and reinforced concrete, in two locations: (Toronto, ON and Vancouver, B.C.)?

3. How would site, environmental, location, and energy efficiency factors influence the process?

4. How much energy is required to demolish/deconstruct respective wood, steel and concrete structural systems using techniques that maximize recycling and reuse?

5. What is the significance of the computed demolition energies?

1.3 STUDY METHODOLOGY AND REPORT STRUCTURE

1.3.1 General Methodology

This report uses a standardization of the demolition process to allow a representative energy expense calculation to be performed. Because buildings are, for the most part, "one-off" creations and are built without prototypes, significant variations in design and construction can be evident between buildings of similar size and occupancy type. Building, infrastructure, and fire codes are typically performance based, and consequently, any number of material types and construction details can be used alone or in combination to achieve the design objective while maintaining code compliance. The net result is that few buildings are exactly alike. As noted in section 2.0, this variation in building configuration has contributed to a very inconsistent industry approach to the demolition process. Like the buildings themselves, no two demolition
projects or the techniques used to effect them are identical.

This study has simplified the possible variations in the process by limiting the scope of analysis to the three materials and applications defined by the previous study, *Life Cycle Energy Use in Office Buildings*. Baseline demolition processes were developed for each of the three assembly materials: wood, steel, and concrete, respectively. The process chosen for each scenario was based on current industry practice, and the quantity, labour and material take-offs for each case were performed by the AIM Waste Management Division of Maple Engineering Canada Ltd., a large international contractor who is very active in Industrial, Commercial and Institutional (ICI) demolition, deconstruction and recycling. The processes and take-offs developed by Maple were cross referenced to the 1996 R.S. Means Facilities Construction Data database and the 1996 R.S. Means Building Construction Cost Data database. Modification and "fine tuning" for anticipated practices at the end of the building's expected life cycle were incorporated to establish baseline approaches which would be reasonable for a demolition time some 50 to 80 years in the future.

The analytical portion of this report consists of the analysis of a series of case studies. The case studies model the application of the developed demolition methodologies to each of the assemblies defined by the *Life Cycle Energy Use in Office Buildings* report. Two approaches - demolition for recycling, and deconstruction for reuse - were assumed to be performed on three assembly types: wood frame, steel frame, and reinforced concrete frame, yielding a total of six cases.

To make the analysis site specific, factors were developed for two locations, Vancouver, B.C. and Toronto, ON and in two thermal regimes, winter and summer.

**1.3.2 Sequence**

The energy calculation methodology basically consisted of the following sequence:

(i) A baseline approach was developed for all six case studies. The baseline approach defined the method by which each demolition case would be effected.

(ii) An examination of ancillary site activities was performed to determine if any related site activities impact the energy expenditures associated with demolition.

(iii) Productivity factors related to demolition were studied and quantitative multipliers developed to address the impact of the factors on each study case. The productivity multipliers which were developed defined the impact of location and climate upon each case study.
(iv) Fuel and energy consumption rates were determined for all of the components of the baseline approaches.

(v) Detailed time and material take offs were performed for each case study corresponding to the baseline approaches.

(vi) The productivity multipliers were applied to each time and material take off to yield location specific machine and manpower time estimates.

(vii) The time estimates developed in step (vi) were multiplied by the consumption rates in step (iv) to determine the total amount of energy consumed, if the baseline methodology was applied to each test case. Fuel consumption to energy conversions were performed using factors developed in previous ATHENA™ studies.

(vii) The computation results were compared to previous ATHENA™ energy estimates developed for the same assemblies, to determine the significance of demolition energy with respect to overall life cycle energy.

1.3.3 Study Scope and Boundary Conditions

To maintain continuity with previous ATHENA™ studies, the scope of investigation has been limited to the same basic structural elements and boundary conditions as those used in the Life Cycle Energy Use in Office Buildings report. Some adjustments have been made to allow specific calculations to proceed, but in general the research was limited to the following areas:

.1 Structure:

The analysis was limited to three structural assemblies: wood frame, steel frame and reinforced concrete frame, as per the engineered drawings provided to facilitate the Life Cycle Energy Use in Office Buildings report. All case studies were limited to the structure without underground parking.

.2 Location:

Two locations were analyzed for demolition energy differences - Vancouver, British Columbia, Canada and Toronto, Ontario, Canada.
3. Timeframe:

The case studies were analyzed for demolition techniques available in 1996, but the baseline methodology which was developed utilized the most energy conservative techniques currently practiced. The baseline methodology also idealized the current processes to account for improvements likely to occur at the actual time of demolition (2046 to 2076). The idealizing assumptions are described in more detail in Section 3.1.

4. Extent of Site:

For the purpose of analysis, the "site" was limited to the physical space occupied by the building structural elements. Only the actual structure itself was analyzed for demolition energy. Site restoration, energy required to transport to the lot perimeter, related activities etc., were not quantified or otherwise included in the estimates. Ancillary activities, environmental concerns, and other related items are discussed to provide a more complete understanding of the study context and limitations, but again have not been quantified.

5. Operations Included for Energy Analysis:

All activities and operations directly and exclusively related to the structural assemblies were included for quantitative analysis. Operations which were applied to other assemblies were not quantified. Operations required to directly facilitate completion of the demolition/deconstruction and removal of material off of the site were included and assumed to be 100% attributable to the process from an energy standpoint. No 'off site' activities were included with the exception of the energy required to transport the demolition machinery to the structure location. Energy required to transport material to end use applications and to Material Recovery/Reprocessing Facilities (MRFs) was deemed to be attributable to the next generation of product as per the previous ATHENA™ Research Guidelines and was therefore not included.¹³

1.3.4 Report Structure

The balance of this report is structured as follows:

Section 2

A brief overview of the demolition industry, current C&D recycling and reuse patterns and considerations related to each assembly material is provided in this section.
Section 3

This section establishes the baseline demolition and deconstruction approaches for each specific structural material type. A description of the assumptions made to allow computation of the demolition energies is provided, as well as a description of the building and various material types. The limitations of each material type and potential for reuse and recycling are described.

Section 4

This section examines the impact of other ancillary construction activities upon the demolition and deconstruction process and establishes quantitative modifiers for inclusion into the baseline process.

Section 5

A review of current C&D machine fuel consumption rates is performed in this section.

Section 6

Various productivity factors which influence the demolition process are examined in this section. The impact of location and weather are examined and multipliers developed for application to the baseline methodology.

Section 7

This section presents the results of the energy analysis computations and the associated conclusions.

Appendix A

A summary of the demolition energy calculations for all of the test cases is provided in tabular form in this section.

Appendix B

The demolition energy 'take offs' are presented in this section.


3 Roodman, op.cit., p. 31.


9 Ibid., pp. 5-9.


2.0 STATE OF THE INDUSTRY

2.1 CONTRACTOR PROFILES

The C&D recycling/reuse industry, both in Canada and the United States, can be generally characterized as undeveloped in comparison to other construction related industries. As noted in Section 1.0, although C&D recycling and reuse has been practiced in various forms for thousands of years, changing resource consumption and utilization patterns have not supported a maturation of the practice. As a result of discontinuous application of 3R principles, the C&D recycle/reuse industry has not developed to a high state of evolution nor is it generally an integral part of the construction process. Rather, demolition (or deconstruction) is often viewed as little more than a nuisance to be completed as quickly and cheaply as possible.

At present, the industry is driven by legislation as well as by market considerations related to disposal (tipping) fees. Legislation is currently in a fledgling state with only one province (Ontario) having comprehensive C&D waste management legislation actually in effect. The requirement for waste auditing, waste management action plans and the like is generally a contractual issue outside of Ontario. In Ontario, Regulations 102/94 and 103/94 stipulate auditing and source separation respectively, but only on projects exceeding 2000 m² in gross floor area.²

The impact of the foregoing situation upon the structure of the industry is the prevalence of a diversity of contractors, waste management practices, and reuse/recycling activities, most which are inconsistently documented. The industry is unregulated and operates without professional standards which has given rise to a two tiered contractor grouping. The majority of demolition contractors are localized, small in size and relatively unsophisticated. These contractors perform machine demolition and sometimes disposal, often operating in conjunction with a waste hauler. Excavation and site work are sometimes performed on other projects using the same type of machines. Contractors specializing in deconstruction share some of these characteristics, particularly small size and local emphasis.³ Deconstruction contractors differ from other demolition contractors because manual labour is the primary means of effecting the work. These contractors are also usually "tied in" to a loosely organized network of material re-users and re-sellers and obviously the accessibility to end-use markets is a primary consideration in their business.

The balance of the demolition industry consists of sizable, well equipped contractors who specialize in machine demolition of large structures. These organizations are typically well equipped and can undertake large projects in remote locations. Although few in number, the large firms perform high volumes of work and are closely allied
with waste disposal haulers and disposal facilities. Some large contractors even own and operate material recovery/reprocessing facilities (MRF's) and/or landfills.

2.2 CURRENT C&D RECYCLING/REUSE PRACTICES

As noted in Section 1.0, current technology allows for some form of recycling and reuse of virtually all materials normally generated during building demolition. Unfortunately, the current levels of C&D material recycling and reuse are very low in Canada. This is due, in part, to the following factors:

- lack of legislation which mandates C&D waste reduction/diversion (with the exception of Ontario);
- design and construction practices which preclude efficient and effective deconstruction and/or source separation;
- a lack of MRF’s and end-use markets for source separated material;
- a lack of acceptance of used materials by owners, designers, contractors and regulatory agencies;
- specified construction schedules which are too short to allow deconstruction and/or source separation to occur;
- accessibility to landfills which have low tipping fees (i.e. private facilities, rural sites and landfills located in the USA).

The Canadian Recycling Resource Disk lists 49 C&D material processors (MRFs), 17 reusers and 91 related entries which are currently in operation. Although this is not a complete listing, it demonstrates the fact that the industry has a high number of small players with a few, larger specialized operators in existence.

Despite the number of C&D recycling/reuse contractors and facilities, their collective lack of capacity and annual volume result in the previously mentioned low rates of landfill diversion. Although accurate, quantitative data is scarce, some studies have attempted to estimate overall generation and diversion rates. One such study indicated a generation rate of 11,186,706 tonnes of C&D waste in 1992 with 4,715,837 tonnes being diverted. A more detailed breakdown of the diverted quantity, however, indicated that 4,510,633 tonnes of the material reported as being diverted consisted of asphalt and concrete, materials which have traditionally been reused as fill or crushed as road subgrade. Less than 3% of building related waste (i.e. wood, gypsum, paper,
etc.) was reported as being diverted. This low, estimated diversion rate was substantiated by discussions with demolition contractors.

C&D waste varies widely in composition and is quite project specific. Figure 2.1 shows the breakdown of constituent materials in a composite of five small ICI projects undertaken in 1993. The large proportion of concrete & rubble shown in Figure 2.1 is due to the prevalence of this material in the projects which were audited. Residential construction shows a waste profile with a greater proportion of wood and packaging materials as seen in Figure 2.2.
The recycling and reuse potential of both types of waste stream is dependent on numerous factors as noted previously, but in general, concrete and asphalt products are likely to be recycled or reused if MRFs with low tipping fees are proximate to the project location. The balance of generated materials are usually landfilled unless a high residual value for certain components exists (i.e. metals or packaged equipment) or an external driver promotes 3R activities (i.e. legislation or contractual requirements).

2.3 REUSE AND RECYCLING CONSIDERATIONS FOR VARIOUS STRUCTURAL ASSEMBLIES

2.3.1 Wood

In general, wood assemblies are typically demolished by machine and the resultant waste products taken to landfill. Urbanized areas, especially in Ontario, have begun surcharging wood waste and in some cases banning receipt of the material in municipal landfill facilities. As a result of this trend, MRFs dedicated to C&D wood reprocessing have begun to appear.
The recycling viability of wood (apart from market considerations) is limited primarily by its cleanliness and purity. Wood wastes are shredded, chipped, or crushed and used for numerous purposes ranging from biofuel to agricultural mulch. The input parameters for most fuel applications are very rigid and do not allow for the presence of hazardous materials, foreign objects (such as metal), or rotten wood.

Reuse of C&D wood waste is very inconsistent at present, and is generally limited to dimensional lumber of large size. Old buildings containing large "old growth" lumber are the most likely candidates for systematic deconstruction which accesses the members for subsequent reuse. Interest in furniture and structures built using old, reclaimed lumber is on the rise and the practice is very prevalent in Mennonite communities in the Kitchener/Waterloo area of Ontario.

### 2.3.2 Steel

Steel has a very high residual value compared to other C&D waste products and hence is recycled or reused if quantities are significant and accessible on a demolition project. Steel structural assemblies are almost always recovered and the decision to reuse or recycle is usually dependent on local market values for steel products.

Recycled steel is usually shipped to MRP’s or directly to a mini-mill where it is transformed into a variety of products. Demolition for recycling is very quick and is usually not limited by construction or design details.

Reuse of structural steel, on the other hand, does occur but it is very constrained by current design practices which specify "new material only" in most cases. Hysteresis or fatigue of structural steel members can occur where the material has been exposed to high intensity/multiple cycle loading such as in bridges and cranes. Steel strength standards have also changed over time necessitating testing of steel members to determine yield strength in high load applications. These factors contribute to low reuse rates because of liability concerns on the part of designers and contractors.

The popularity of field welded connections also stymies reuse of members in their entirety, due to heat stress introduced during demolition and the difficulty in torch cutting large cross sections. Even bolted connections pose practical problems due to corrosion and lack of accessibility, both of which increase the length of time required to perform deconstruction. Disassembly of structural steel frames for reuse is slow and dangerous, and consequently expensive.
2.3.3 Concrete

Approximately 73% of C&D concrete waste produced in 1992 was diverted from landfill and recycled or reused.\textsuperscript{4} Cast in place concrete is generally reduced in size "on site", to allow transport and then shipped to an MRF where it is crushed and used as feedstock for other processes such as masonry unit fabrication. The process is quick and relatively inexpensive.

The downside to concrete recycling is the very high energy toll associated with the recycling process and the transport of both feedstock and finished products. Producing new concrete using virgin Portland cement and crushed recycled concrete aggregate requires the same amount of energy as producing virgin concrete (0.5 - 1.5 GJ/ton).\textsuperscript{7} The very high density of concrete also diminishes the environmental advantages of recycling if significant transport is required.

Reuse of concrete is theoretically possible for precast members and indeed some reuse does occur, particularly in the case of smaller structures. Practical problems associated with more widespread reuse of this type include lack of adaptability in terms of loading profile, fragility of precast concrete members, difficulty in transport, as well as the common presence of field installed shear ties and hooks which require removal.

Reuse of cast in place concrete is generally limited to crushing and placement as fill or site dressing. Again, the high density of the material makes transport to other locations problematic. This point is discussed in greater detail in Section 3.3.1.1.


\textsuperscript{4}The Canadian Recycling Resource Disk. (Toronto: Canadian Recycling Handbook and Directory, 1995.)


\textsuperscript{6}Ibid, pp. 2-23.

3.0 STANDARD DEMOLITION / DECONSTRUCTION METHODOLOGY

3.1 GENERAL

It was alluded earlier that the C&D waste management industry was undergoing significant changes as a result of extraneous forces. This trend will undoubtedly continue as environmental concerns and energy scarcity drive all industries to adopt more sustainable resource management practices. As noted in the earlierATHENA™ reports, it is somewhat problematic to project industry practices at the end of a current building's anticipated lifespan of 50 to 80 years. Nonetheless, it is inevitable that certain trends will become standard practice. In particular, the thrust for higher levels of landfill diversion will likely culminate in the ban of all recyclable and reusable material at urban landfill sites. It is also likely that the maturation of end use markets for post-processing C&D products, will occur coincidentally to the establishment of a more stable supply of diverted raw materials. The economic viability of C&D waste reuse and recycling will increase significantly, when this occurs.

In developing the baseline process used for the actual energy estimations, the above extrapolations were used to make several idealizing assumptions as follows:

Assumption 1

*The buildings in question will be subject to demolition practices based on 100% recycling or reuse.*

For the purposes of this study, the following definitions will be used:

Demolition - The reduction of a free standing building or structure into smaller constituent elements located at or near grade.

Selective Demolition - The demolition of discrete components of a building or structure in order to separate them from the balance of the generated waste.

Deconstruction - The systematic dismantling of a building or structure in order to minimize damage to the removed components and hence maximize reuse potential.

Recycle - Transformation of materials generated during demolition into another saleable or otherwise useable product by the application of external processes or treatments.

Reuse - Use of a material or product removed from a structure during demolition in
another application without significant alteration.

In the case of recycling, it was assumed that selective demolition would be employed to source separate generated materials and all of the materials would be subject to recycling. In the reuse case, the building was assumed to be deconstructed and the materials prepared for reuse in another incarnation.

This assumption is valid in the two urban area test locations (Toronto and Vancouver) since current trends have already severely restricted the disposal option in both of these areas. In the case of rural communities and remote locations, this may not necessarily hold true. The specifics of each material type are discussed in Sections 3.3 to 3.5, but in general, several construction details inherent in the frames analyzed, would preclude 100% reuse, and could diminish the recycling potential as well. An example of this, is the use of concrete topping on the upper floors of the wood structure. The project take-offs assume separation of this composite detail using a combination of manual labour and machine time. In reality, even if a bond breaking agent was applied at the time of slab placement, it would be exceedingly difficult to remove the concrete without destroying the underlying 16 mm plywood sheathing.

The example cited brings up the issue of "design for deconstruction". For the purpose of this study it was assumed that all of the technical barriers to deconstruction inherent in the designs provided could be overcome, with the exception of the monolithic concrete elements. This is a necessary simplification to meet the 100% recycling/reuse objective. In reality, the waste streams (for recycled material) would likely be contaminated to some extent, and likewise, some of the wood structure, and to a lesser extent the steel structure, would be unsuitable for reuse.

To achieve 100% reuse or recycling, buildings must be designed and constructed to allow easy deconstruction without damage to the components. "Design for deconstruction", although inherent in ancient structures, is still a radical progression over current design practices. Reuse in particular, is contingent on buildings and their constituent components being adaptable to new applications. While this is less significant in the case of the structural elements examined, it is crucial to architectural components and interior assemblies which undergo alteration on cycles which are much shorter than the life cycle of the overall building. In a market and time based economy such as the one that currently exists, large inputs of new material, refurbishing labour or modification to end use environments are highly undesirable in the case of most materials. Certain exceptions apply such as in the case of very high value components or items of historical value. As a general rule, however, materials must be relatively easy to separate from the overall structure and must be amenable to reuse without repair, or to recycling without application of additional sorting.
The above points are borne out by practices noted at building material recycle and reuse centres. Bob Sawatsky of the Reuse Building Supply Centre in Scarborough, a successful, "for profit" building material reuse store, notes that a key to success is the acceptance of "quality" materials, ie: generally undamaged materials that are saleable in their received condition. Similarly, the cost of delivering material to a recycling facility is directly proportional to the degree of cross contamination or mixing. Some separated waste materials are much more valuable than mixed materials because an additional time consuming separation step can be avoided at the facility. Try Recycling and Harkow Aggregates in London, Ontario and Toronto, Ontario respectively, are two examples of C&D recycling facilities which accept both source separated and mixed or "commingled " material. In the latter case, a 100% surcharge is applied, which brings the tipping fee up to the maximum amount charged for any material. In the former case, concrete rubble, asphalt, roofing materials, and a number of other homogeneous, source separated materials, are accepted free of charge. The supply of quality feedstock in both the reuse and recycling cases is, in fact, the critical determinant for an MRFs viability.

Due to the difficulty in deconstructing buildings possessing current construction detailing, most demolition projects use a combination of reuse, recycling and disposal. Generally, high value items which can be easily removed will be separated for reuse if sufficient time is provided in the project schedule. Materials damaged during removal due to inaccessibility, bonding to other materials (composites), or connection details which are not suitable for dismantling, are separated for recycling. The balance of material is disposed in landfill.

The second assumption drawn regarding future practices is as follows:

Assumption 2

The impact of fuel scarcity on demolition practices in the future will be a much elevated focus upon fuel conservation and requisite modification to the demolition process.

It is conceivable that mechanized demolition will not be feasible at the end of the study case life cycles. At present, 82% of the energy consumed in Canada is derived from non-renewable sources and 75% is derived directly from fossil fuels. Since electricity from the hydroelectric grid is generally unavailable at demolition sites (disconnection of all power is performed prior to project commencement for safety reasons) the fossil fuel consumption percentage cited essentially rises to 100% for the demolition industry. All large demolition machinery uses hydrocarbon fuels; hand tools are powered by diesel consuming compressors; and site electricity is usually provided by portable gasoline powered generators. Similarly, heating is performed using propane fuelled "salamanders", and saws and torches are also all powered by hydrocarbon fuels.
Some studies predict that current reserves of oil and natural gas (both known and discoverable) could be consumed within 30 to 50 years and that even coal is only expected to last another 100 years.4 Other forms of alternative energy are unlikely to provide a suitable substitute to fossil fuel with the possible exception of hydrogen. Although the exact lifespan of fuel reserves is difficult to predict, it is reasonable to assume that fuel will be much scarcer in 50 to 80 years than it is currently. Given this, it is likely that future site operations will be modified significantly over current practices to minimize fuel consumption.

For the purposes of this study it was assumed that sufficient fossil fuel still existed at the time of demolition to utilize traditional forms of demolition machinery, however, the following impacts of fuel scarcity are anticipated:

(i) Extreme fuel scarcity will preclude transport of high density concrete to off-site reuse facilities.

(ii) On site processing of low density wood material will be performed to increase the transport density, thus minimizing the number of transport cycles (and hence fuel consumption).

(iii) All machine run times are at peak output with minimal idle time. This point and related items are discussed in greater detail in Section 6.0.

Although fuel consumption will probably be much lower for future demolition machinery than today, it is impossible to quantitatively estimate the specific future consumption rates. To allow the energy calculations to be performed, current fuel consumption rates were used with the knowledge that the resultant energy estimated would be accurate for 1996 but higher than actual for the end of the projected life cycle.

3.2 DESCRIPTION OF TEST CASES

The building analyzed is a generic, three storey office building of approximately 4620 m² gross floor area. A detailed building description is provided in the previous ATHENA™ study: *Life Cycle Energy Use in Office Buildings.*

The demolition energy study focused on three alternate structural systems as described below and was performed on the building frame only as noted in Section 1.3.3. The test cases were limited to the structures themselves, exclusive of the site, site infrastructure and underground parking facilities. Since the study is structured to determine demolition energy specific to the assembly rather than the process, the
analysis has not been extended to restoration of the site and related activities. The relative impact of some relevant site activities is discussed in general terms in Section 4.0.

The analyzed structure was delineated as per the previous life cycle studies to allow direct integration of the analysis results into the ATHENA™ database. The general categories analyzed were:

- Below Grade Horizontal Structure
- Below Grade Vertical Structure
- Above Grade Horizontal Structure
- Above Grade Vertical Structure
- Miscellaneous

Details of each structural type are provided below.

3.2.1 Wood Structure

- Plywood floor and roof decks with concrete topping to floors
- Prefabricated engineered wood joists (TJIs)
- Glulam beams and columns
- Wood framed, plywood sheathed shear walls

3.2.2 Steel Structure

The steel structure was assumed to be constructed with light weight components, open web joists and HSS columns, rather than the heavier sections commonly used in larger steel framed buildings:

- Galvanized steel roof and floor decks with concrete topping to floors
- Open web steel joists
- Wide flange beams
- Hollow steel section columns
- Steel braced shear walls

3.2.3 Concrete Structure

- Cast in place reinforce concrete floor and roof slabs with slab bands
- Cast in place reinforced concrete columns
- Cast in place reinforced concrete shear walls
3.3 BASELINE METHODOLOGY

As noted previously, the baseline methodology was developed using a case study format. It is important to note that the test cases are hypothetical models which are based on industry practices. No actual, specific, demolition was performed to develop the baseline methodology. Each test case is described, however, as if it were an actual project in order to provide a clear understanding of the modelled process. The case studies describe the steps involved as if a project was actually undertaken. The energy expenditure calculations were subsequently performed on the hypothetical project data. The specific baseline methodology for each structural type is described in the following sections.

In general, the recycling model entailed selective demolition of the material types to achieve source separation on site, followed by on-site processing for densification. Transport of all materials off site for subsequent processing at a Materials Recovery/Reprocessing Facility (MRF) was assumed.

The reuse case involved application of manual labour augmented by machines to remove all discrete elements intact. The removed materials were assumed to be sorted, stockpiled and loaded for transport to reuse facilities or end-use directly. Concrete was deemed to be processed and reused directly at the site for clean fill and site dressing. This proposed reuse of concrete "on-site" poses several methodological questions with respect to overall LCA which are discussed in greater detail in Section 3.3.2.3.

All of the reuse and recycling operations were assumed to begin with a completely exposed structural frame. This partitioning of the process is not entirely realistic, particularly in the case of the wood structure. Current selective demolition (for both reuse and recycling) occurs simultaneously on various building components. For example, entire wall assemblies are often removed by an excavator equipped with a grapple and subsequently source separated - i.e. removal of brick cladding from wood framing by simply lifting the wood framing vertically after an entire wall has been flipped face down. Similarly manual removal of mechanical fixtures can occur in one section of a building while machines are used to remove exterior cladding in another portion. Safety concerns and accessibility are the dictating factors in the scheduling of individual tasks and it is impossible to generalize since each building case is unique.

The individual steps and processes assumed for each case study are summarized in the following sections. Each approach has been portrayed as a series of sequential steps for ease of depiction, but in actuality, demolition/deconstruction is a contiguous process with many "steps" occurring simultaneously or overlapping. Some of the steps were used in all of the case study approaches discussed and these are noted accordingly.
3.3.1 Steps Common To All Case Studies

1. Site Mobilization and Set-Up

The first step proposed in all of the cases analyzed was the delineation of the area of work, transport of materials to the site (including equipment), set-up of site services, environmental protection measures and safety installations as well as set up of a site trailer.

From an analysis standpoint, it is somewhat difficult to differentiate between indirect activities which are peculiar (or in the LCA sense attributable) to the process and those which are attributable to the assembly.

The erection of protective fencing (as per National Building Code NBCC 1995 requirements), a serviced site trailer, environmental protection measures, and the establishment of a fuel depot (if required), are common to all three material types and processes, but also to non structural building components. As the structural elements comprise only a portion of the overall building and likewise a portion of the overall demolition energy expended, the energy debits for the noted items should, in practice, be apportioned to all of the materials in the building on the basis of relative demolition energy magnitude. In other words, the elements with the highest proportion of individual demolition energy should incur a proportionally higher share of the common demolition energy component.

An analysis of demolition energies for all other building components (exclusive of structural systems) is beyond the scope of this study, hence it is difficult to ascertain a realistic proportion of the "mobilization energy" as well as the recurring energy (during the course of demolition) which is attributable to the structural systems only. As a simplification, common mobilization tasks have been omitted from further quantitative analysis as per the boundary conditions discussed in Section 1.3.3. The qualitative impacts of indirect activities are discussed further in Section 4.0.

The mobilization energy expenditures directly associated with demolition were included in the subsequent quantitative analysis and these include:

- The assumed transporting or "float" of demolition equipment and off loading at the site. This presumed the use of a 14.63 metre (48 foot) trailer hauled by a 261 KW (350 H.P.) turbocharged diesel tractor truck from the contractor's yard. The average haul distance was assumed to be 73 kilometres (45 miles);

- Demolition equipment set-up and use of float trucks while on site;
.2 Project Activities

The following activities were accounted for over the duration of the proposed project:

- Equipment refuelling, maintenance and attachment installation/changes (grapples, buckets, extension booms, etc.);

- Project management and site supervision/control consisting of site supervisor and use of a pick-up truck for the duration of the project. A relatively high intensity of use was assumed to account for miscellaneous trips off site which would support on-site activities (i.e. fetching spare parts, food, and contract administration duties).

.3 De-Mobilization

Upon conclusion of reuse/recycling site activities, the following direct demobilization activity was assumed:

- Loading of equipment on float trailers for transport back to the point of origin (contractor's yard).

Transport of generated products (i.e. reusable building components or processed wood/concrete) from the building location to the site perimeter, was not included in the analysis since transport inputs are considered to be "up front" expenditures for feedstock used by other industries.

3.3.2 Wood Structure - Recycling Case

The above grade wood structure was assumed to be subject to demolition, subsequent to removal of all exterior cladding and interior systems and finishes. The proposed process of demolition was standard dismantlement using 2 Caterpillar 325L excavators equipped with hydraulic demolition grapple attachments and reach stick attachments (integral to grapple). The below grade structure was assumed to be excavated, reduced to rubble by impact hammers and transported off site for recycling at an MRF. The details of each step are provided below:

.1 Concrete Topping Removal

This initial step entailed the use of a four man crew using air powered chipping hammers to remove the concrete topping from the second and third floor sheathing. The air hammers were powered by an Atlas four cylinder compressor and the separated
concrete was assumed to be collected and removed by two 14.8 kW (19.8 H.P.) skid steer loaders equipped with buckets.

As mentioned earlier, it was assumed that separation of the topping from the sheathing was possible without undue cross contamination.

.2 Above Grade Structure

After floor topping removal, the building superstructure was assumed to be demolished using two Caterpillar 325L excavators equipped with grapples. The designated sequence was simultaneous removal of the perimeter beams and roof joists (third floor) to the inside column lines, followed by removal of the shear walls. The process was repeated cyclically for all floors and column lines until the entire superstructure was brought to grade.

Metal fabrications and devices such as shear wall anchors, nails, joist hangers, etc. were not specified for source separation since on site processing using a tub-grinder was deemed to have been performed. The metal residue left mixed with the processed wood, was assumed to be removed by magnetic extraction at the MRF.

.3 Below Grade Structure

All of the concrete structure located below grade was specified to be exposed by excavation using a Caterpillar excavator equipped with a bucket attachment. One of the excavators was specified to be equipped with a 5.2 kJ hydraulic impact hammer which was assumed to break the reinforced concrete to 380 mm nominal sized pieces for transport off-site. To facilitate loading and separation, the concrete breaking operations were deemed to be augmented by a labourer using a gasoline powered Skil saw to cut any loose reinforcing steel tying the broken concrete pieces together. This process was assumed to occur on an "as required" basis. The concrete pieces were then transported from the structure location to Tridem tandem wheeled dump trucks using one of the excavators equipped with the bucket attachment.

The reduction of the concrete elements to 380 mm nominal size is a standard practice currently and allows use of the product in both recycling applications (at an MRF) or reuse applications (clean fill). It was deemed that breaking to a smaller nominal size to increase the density would not be productive even in an energy deficient environment because the truck's carrying capacity is only 16-18 tonnes. Further densification would therefore only result in trucks leaving the site without a full load (volumetric). It is conceivable that higher carrying capacities may be allowed in the future but this would undoubtedly have other negative impacts in terms of shorter machine life cycles, roadway and bridge damage, and safety, and hence was dismissed from further
consideration.

.4 Wood Stockpiling and Preparation

This step proposed the use of the excavators equipped with grapples to stockpile the wood in a staging area adjacent to the building site. A 261 kW (350 H.P) Innovator tub grinder was proposed to be floated onto the site and used to process the broken wood elements into 50 mm nominal size chips for transport off-site. One of the excavators, equipped with a bucket was allocated to load the chipped material into a tractor trailer dump truck for transport to an MRF.

As alluded earlier, the chipping operation could be construed as a process which should be charged (in the life cycle energy sense) to the next generation of product. In this case chipping would be required only to densify the material for economical transport (both in financial and energy terms). This is the case for actual projects today and would undoubtedly be even more so in the future. Given this, the overall energy debit for this phase of the demolition was attributed to the demolition energy phase of the Life Cycle as per Section 1.3.3.5.

The overall timeframe proposed for this case, as described above, was approximately five weeks.

3.3.3 Wood Structure - Reuse Case

The general methodology employed for this approach was a more methodical separation of all of the elements with the aim of minimal damage and cross contamination of removed products. This was accomplished by proposing the use of manual labour to supplant machine time. Removal of below grade structural elements (concrete) was virtually identical to the recycle case as was the removal of the second and third floor concrete floor toppings. The primary difference in the below grade work was the use of a crushe to reduce the concrete rubble to a smaller nominal size which was amenable to reuse, on-site, as fill and top dressing.

The above grade structural elements were deemed to be primarily dismantled by manual labour and loaded on flat-bed tractor trailer trucks for transport off-site. A more detailed description of each operation is included below:

.1 Concrete topping removal - Second and Third Floors

This operation was identical to 3.3.1.1.
2. Above Grade Structure

The above grade structure was assumed to be dismantled by a crew of ten labourers equipped with standard carpentry tools. The process modelled was a vertically sequenced de-construction as per Section 216 of the Ontario Health and Safety Act (OHLA). The labour crew mechanically removed fastening devices beginning on the roof level and then utilized a truck mounted hydraulic crane to transport the freed elements to grade. A forklift was specified to move the elements to the stockpile area. The individual structural elements were assumed to be de-nailed, sorted and bundled by size and structural grade. The sorting and bundling operations were facilitated by use of a second forklift which loaded the bundles on to a transport truck equipped with a flat bed trailer.

3. Below Grade Structure

The concrete structure was 'taken off' for removal below grade by excavation of the footings by an excavator equipped with a bucket as per the previous case. Another excavator equipped with a hydraulic hammer was assumed to have reduced the excavated elements and slab-on-grade/below grade elements to 380 mm nominal size. Upon completion of this task, the rubble was stockpiled, on-site, adjacent to a crushing machine.

One of the excavators equipped with a hydraulic crusher jaw attachment was allocated to reduce the rubble to approximately 200 mm in size to prepare for final crushing. Only approximately 50% of the concrete would require the preparatory crushing phase since all of the slab toppings would have been reduced to less than 150 mm minimal size during chipping. The other excavator, equipped with a bucket attachment, was specified to have loaded the reduced rubble into a Nordberg impact crusher which crushed the rubble to a 63 mm nominal size. A 59 kW (79 H.P.) Caterpillar 426B backhoe loader was allocated to transport the crushed material back to the footing/foundation wall excavation site where it was placed as fill. It is notable that approximately one Tridem truck load (16 tonnes) of concrete would be surplus at the end of the proposed crushing operation, because of lack of insufficient excavation volume. This balance was deemed to be left on-site (stockpiled) for future re-use.

The ‘on-site’ reuse of crushed concrete was incorporated because this is the most energy efficient, logical reuse application. Transport of dense, concrete rubble is only performed today, if on-site requirements do not exist, and as mentioned earlier, expected fuel conservation requirements in the future will only exacerbate this trend.

It was decided to leave the energy expenditures associated with crushing as debits against the first life cycle of the concrete. Because it was felt that the lack of
re-usability of concrete (as anything other than fill) and also the extremely high density were properties inherent and attributable to the product. Steel and wood can both be reused as a result of good construction detailing (i.e. "design for deconstruction") but this is not the case for cast in place concrete.

Concrete, once placed, is essentially non re-usable and there is a very heavy energy toll associated with recycling as noted in Section 2.3. The most prevalent current reuse application for cast in place concrete is as "on site" fill. It was felt that crushing of the concrete did not significantly transform its basic characteristics and hence this process qualified as reuse in accordance with the definition provided in Section 3.1. This assumption is open to some debate since crushing can be considered as a form of processing, however, in keeping with current industry practice and nomenclature the aforementioned practice was classified as reuse.

The overall schedule assumed for this deconstruction case was ten weeks, clearly demonstrating the need for increased time allowance for reuse operations.

3.3.4 Steel - Recycle Case

The general approach proposed for this case is very similar to that of the wood structure - recycle case. The primary difference was the use of hydraulic shear attachments on the excavators for the superstructure removal. Once placed on grade, the steel was assumed to be cut by the shears to facilitate transport. The specific details are provided below:

.1 Concrete Topping Removal

As per 3.3.1.1.

.2 Above Grade Structure

All of the above grade structural elements were specified to be removed sequentially using a single Caterpillar 325L equipped with a hydraulic shear. The shear was used to selectively cut and pull individual members away from the structure. A second 325L also equipped with a shear, was assumed to cut the dislodged members into smaller sections for loading onto a transport truck. The cut sections were then loaded on to the truck using an excavator equipped with a grapple. The demolition sequence proposed was the same as that noted for the wood recycle case.
.3 Below Grade Structure

As per 3.3.1.3.

The overall time required to undertake this demolition approach was assumed to be 6 weeks.

3.3.5 Steel - Reuse Case

This proposed scenario entailed deconstruction (dismantling) of the bolted steel frame superstructure subsequent to removal of the concrete floor toppings. The process was relatively slow due to the number of connections and the mass of the members which makes the work onerous and somewhat dangerous. The below grade concrete structure was assumed to be excavated, crushed and reused on-site as clean fill.

.1 Concrete Topping Removal

As per 3.3.1.1.

.2 Above Grade Structure

This task proposed the use of two crews of four personnel equipped with pneumatic ratchet drivers. Two Atlas compressors were specified to provide compressed air via hoses to the labour crews. The dismantling process involved removal of the roof deck followed by the roof joists, intermediate beams and perimeter beams. Since all connections were bolted, the dismantlement required manual removal of all bolts followed by attachment of a sling. A truck mounted hydraulic crane was provided to lift the steel members to grade where a forklift carried them to the stockpile area.

The open web steel joists used for the roof structure were assumed to use shop welded hangers which were bolted in place. It was also assumed that no field welding was performed at the time of original erection.

Upon placement of the members on grade in the stockpile area, the steel members were deemed to be sorted and prepared for transport to an off site reuse application. A forklift was used to sort the steel and bundle it for transport. A transport truck equipped with a flat bed trailer was then proposed to be loaded with the sorted steel and the material was moved off site.
.3 Below Grade Structure

The below grade concrete structure was excavated, crushed and reused as per 3.2.2.3.

The anticipated duration of this case was approximately ten weeks.

3.3.6 Concrete - Recycle Case

This case, is in essence, an extension of the concrete recycle subsections presented previously. The concrete frame was specified for reduction to grade using two Caterpillar excavators equipped with hydraulic impact hammers. The reduced material was then assumed to be stockpiled and loaded into trucks for transport off site. Below grade demolition was as per previous examples. The specific details are identified below:

.1 Above Grade Structure

The entire above grade structure was assumed to be demolished using a Caterpillar 325L excavator equipped with a hammer attachment. The proposed sequence was similar to that specified for the wood recycle case - roof slab fracturing and separation followed by removal of the perimeter beams and third floor horizontal elements to the inside column lines. A "top-bottom" removal of horizontal elements was followed by an "outside to inside" demolition of vertical elements. It is salient to note that the precise sequence of demolition is difficult to predict and is usually left to the discretion of the equipment operators. Concrete strength (actual) can vary significantly as can soil conditions which affect excavator stability and power. The process is typically adjusted "on the fly" as the operators experiment with differing techniques as the project progresses.

The specified nominal size of concrete rubble would be 380 mm after reduction by the impact hammer. As in the case of the foundation recycling in the other examples, separation of the rubble by manually cutting the loose reinforcing steel was required using a gasoline powered Skil saw equipped with a carbide blade.

The rubble was proposed to be stockpiled and a Caterpillar 325L excavator equipped with the bucket attachment was assumed to load the material into 350 H.P. Tridem tandem wheeled dump trucks for transport to an off-site MRF.
Below Grade Structure

As per 3.3.1.3.

The above demolition process was anticipated to take five weeks in its entirety.

3.3.7 Concrete - Reuse Case

As discussed earlier, the reuse of concrete is problematic due to the material's density and lack of adaptability. This is particularly true in the case of cast in place concrete. The monolithic construction (tied concrete slabs, columns and shear walls) used for the study case precludes any kind of reuse other than as fill material.

The only other realistic reuse of the concrete elements in question would be to utilize the entire existing frame as the structural skeleton of a new building on the same site. In the context of the ATHENA™ study, however, this would be considered as renovation or refurbishment rather than demolition followed by reuse. Since this would be beyond the scope of the demolition energy study undertaken herein, it was not given further consideration.

The reuse scenario applied, instead utilized precisely the same demolition methodology as the preceding recycling case. The additional step of crushing the large rubble to 63 mm nominal size aggregate was included as was placement in the excavation locations. The specific details are provided below:

Above Grade Structure

Initial steps were as per 3.3.5.3. Subsequent to breaking the material into 380 mm nominal size pieces, a 325L excavator equipped with a bucket attachment was proposed to place the rubble in the stockpile area. A 325L equipped with a set of hydraulic crusher jaws was then reduced the material to 200 mm in nominal size. The 200 mm rubble was then assumed to be loaded into a 75 KW (109 H.P.) Nordberg City impact crusher for reduction into 63 mm nominal size aggregate. The processed aggregate was loaded by a Caterpillar 426B backhoe and placed in the excavation locations.

The balance of the crushed material (that which would not fit into the footing/foundation excavation) was assumed to be stockpiled on site for future re-use.

The overall timeframe anticipated for this scenario was a total of 6.5 weeks.


4.0 ANCILLARY ACTIVITIES

4.1 GENERAL

The demolition/deconstruction methodology presented in Section 3.0 was limited to the specific task of deconstructing/demolishing the structural frame of the building only. As noted, the demolition process is, in actuality, a series of linked tasks which are integrated with a number of related activities. These related activities impinge upon the demolition process and provide a framework within which the overall demolition project is executed.

This section of the study examines some of the more significant ancillary activities, and reviews current trends and practices. As with the demolition/deconstruction task itself, it is difficult (if not impossible) to accurately predict future practices, therefore the potential impacts upon current demolition energy are discussed.

As per Section 1.3.3, the quantitative impacts of the ancillary activities have not been calculated or included in the energy estimates. This section is included to provide insight into the energy implications of the entire demolition process and to help define the limitations of the demolition energy analysis performed.

4.2 ENVIRONMENTAL PROTECTION

Demolition activities, although large generators of solid waste, have typically not required extensive environmental review or consideration. This is primarily due to the fact that demolition occurs on a site which has already been through the Environmental Assessment process (if applicable) and is generally occurring in an area which already has experienced the major environmental impact of alteration from the natural state to the built environment. By the time the building enters the phase of its life cycle where demolition is required, the surrounding environs are invariably developed.

This notwithstanding, the demolition process often deals with potentially hazardous and quite often, regulated materials, which have been integrated into the building or accumulated on the site. Site activities are regulated by both the Federal Environmental Protection Act and by individual Provincial Environmental Regulations as well as the Occupational Health and Safety Act. In general work must be carried out in a fashion which is safe to the workers, public and adjacent properties, and which prevents discharge of pollutants to the air, soil or water (including municipal infrastructure if applicable).
The following sections discuss the most common environmental concerns during demolition:

4.2.1 Fuel Supply/Storage

Demolition sites employ two methods of fuel supply. The most common is the use of a fuel truck which periodically visits the site and supplies diesel fuel, gasoline and lubricants. Fuelling is performed by pump (manual or electric) and transfer occurs directly from the tanker truck to the machinery. Fuel trucks are typically equipped with spill kits consisting of absorbent matting, protective clothing and surfactants.

The second practice currently used, particularly on larger projects, is the establishment of an on-site fuel depot. This typically consists of several 250 litre fuel drums equipped with hand pumps and hoses, located in an accessible, but not vulnerable, corner of the site. A proper fuel depot consists of an above grade enclosure surrounded by a small berm to catch spills and is lined with an impermeable membrane (typically EPDM). More often than not, however, the drums are simply placed on grade and spills are dealt with by excavating and disposing of contaminated material upon project completion.

In both of the above cases, practices are not anticipated to change significantly with time. The only exception is the probable future enforcement of safe spill containment practices. In either case the overall energy expenditure attributable to the building assembly demolition practices is likely to be negligible.

4.2.2 Stormwater Management and Erosion Control

Excavation of below grade structural components and site cover (i.e. asphalt parking lots) exposes soil to potential erosion and erosion/sediment control measures must be implemented if required. In practice, the grade of most building lots is very low and the greatest potential for erosion is from removal of surface cover as opposed to excavation. Since parking lots are typically 5% in grade or less, the likelihood of erosion control measures being required is minimal. Interviews with several contractors indicated that erosion control and sediment control measures are not normal considerations in planning a demolition project. The increased grades of the Vancouver region increase the likelihood of sediment control measures being required, but interviews with contractors who perform demolition in the area indicate it is also not a normal working practice at the present time.

Future trends in this area will undoubtedly be toward more stringent application of principles in use today as the awareness of habitat loss due to siltation increases. Sediment control is fairly well developed with numerous construction related standards
available such as the Ontario Provincial Specification Standards. The most common practices which would be employed on a demolition site are as follows:

*Siltation Blankets and Fencing* erected at the perimeter of cleared site to prevent sediment from flowing onto adjacent land. Typically a geotextile filter fabric is affixed to a flexible fence and anchored to grade with a granular backfilled trench.

*Rock Check Dams* are mounds of rip-rap with a leading edge (upstream) of crushed limestone covered with filter cloth. The dams are placed in ditches and drainage channels to intercept (filter) entrained sediments but allow drainage of surface and storm water to continue unabated.

*Sediment Basins* are constructed depressions lined with granular material and geotextiles to capture sediment laden water and allow settlement under quiescent conditions. These devices are typically constructed only if large sediment loads are anticipated.

All of the above could be foreseen as being more commonly utilized in Vancouver in the future. This is due to the current trend to construct buildings on increasingly steeper lots (as level land area becomes unavailable) and on mountainsides. The impact (in energy terms) will be the application of the construction energy and recurring energy (energy to maintain) to the site specific demolition process. Since this activity is only indirectly related to the structural elements it would be difficult to assign a representative energy allocation, however.

Given the small percentage of projects requiring siltation abatement and the distribution of energy to other activities (site restoration as well as non-structural components) it is likely that this activity will be negligible in a structural assembly context. In quantitative terms, no energy adjustment is required.

### 4.2.3 Contaminated Materials

The case studies analyzed, all assume a construction date of 1996 and likewise assume that all of the components utilized are of a current vintage. None of the structural systems analyzed contain any material which would currently be classified as hazardous or contaminated. This notwithstanding, it is useful to examine some of the more common types of contamination encountered for two reasons:

1. Materials which are currently considered non-hazardous or inert may be deemed hazardous in the future.

2. The building use may change over time introducing potentially hazardous
materials into the formerly "clean" building environment.

The contamination issue will therefore be reviewed qualitatively and its relevance to current demolition activities discussed, but it will not be incorporated into the case studies in any other way.

In the case of older structures, the remediation of contaminated property and abatement of hazardous materials from within the building is an integral part of the demolition process and is often tendered in the same contract. Most demolition contractors sub-contract this work to speciality firms who decontaminate the building prior to demolition commencement.

Typical materials encountered include:

- **Asbestos** in a variety of forms such as shingles, cladding, floor tiles, insulation and fireproofing.

- **Poly Chlorinated Bi-Phenols (PCB's)** found in lighting ballasts, transformer carcasses and power supply components.

- **Contaminated Soil** which can be impregnated with coal tar residue, phenols, hydrocarbons, solvents, heavy metals, or any number of other process chemicals.

- **Biohazards and Biocides (Pesticide Residues)** could be present in soil and/or absorbed in building materials.

- **Lead** typically found in paints, noise baffles, and electromagnetic shielding applications.

- **Chemical Wood Treatments** - see following

The above is a short, partial listing of hazardous materials encountered in a variety of applications in older buildings and to a lesser extent in newer buildings. The more specific structural applications are discussed by material type below:

.1 Wood

Structural wood is the recipient of an array of treatments and preservatives designed to enhance longevity and performance. Aside from the obvious problem of 'off-gassing' throughout the first life cycle, these treatments are the largest impediment to future reuse and recycling of the product as previously noted in Section 2.3.

In terms of recycling, the presence of contaminants in the wood elevates the risk of
toxic contamination of the processed end product. This subject is the source of considerable discussions (and debate) within the industry and is considered by some researchers to be an imaginary problem. George Molnar of Try Recycling in London, Ontario indicates that regardless of the presence of contaminants on incoming wood, the concentration in the processed end product is invariably below Ontario Ministry of Environment and Energy (MOEE) threshold standards. This is due to the dilution of the contaminated wood by the addition of clean wood during the processing operation. In this case at least, the cliche, "dilution is the solution to pollution", holds true.

The case of reused wood presents a different set of problems, however, since the wood is not processed into another product. If the wood is very severely contaminated it may not be amenable to reuse at all or may require significant applications of energy to ready it for reuse. Removal of biocides (on both old and newer lumber) and lead based paints (on old lumber) are examples of this type of problem. It is difficult to generalize on the issue since the type and level of contamination is case specific, however, generally three options are available:

- Trim and reuse "as is" - This is a viable option if the lumber is not damaged severely and another application can be found. Piers and utility poles (creosoted) and pressure treated bridge timbers are examples of this category;

- Trim and re-mill - Typically, old lumber which has been exposed will require trimming to size to new applications and to remove damaged sections. The balance of the wood is then re-milled, either to a large dimension close to the original size or to smaller dimensional lumber. Discussions with Weber Demolition Ltd. of Elmira, Ontario and several other wood working enterprises in the Elmira area (a Mennonite community north of Kitchener, Ontario which has a strong tradition of wood reuse) indicates that a 10% loss of wood is typical in re-milling treated dimensional lumber;

- Reprocessing/disposal - The wood, if heavily contaminated, can be chipped for reprocessing, burned as fuel, composted, or as a last resort, landfilled.

2 Steel

Steel is very dense and for all practical purposes impermeable, therefore contamination of structural steel is almost always a case of surface treatments or spill contamination which must be removed prior to the reuse or recycling phase. Surface contamination can be as a result of process chemical spills or corrosion which has entrained contaminants. Generalizing the nature of contamination is impossible because the types of contaminants are as varied as the processes themselves. Surface treatments consisting of lead based paints and asbestos fireproofing were commonly used in the past but the practice has been discontinued for some time.
3 Concrete

Concrete has the same contamination profile as steel, except that the porosity is much higher increasing the possibility of surface contamination. Also concrete is quite reactive to certain chemicals, particularly sulphates, which can cause an increase in porosity and a consequent increase in the possibility of contaminant impregnation.

It is noteworthy to consider that current knowledge of hazardous materials is very much limited by current medical knowledge. Long latency times for symptomatic response to hazardous materials have been observed in the past (i.e.: asbestos) which masked the material’s real toxicity. This situation may also occur with materials which are in prevalent use today.

4.3 NOISE CONTROL AND ABATEMENT

4.3.1 Current Practices and Implications

Construction machinery and construction activities are a significant source of noise and in the case of demolition, levels can reach 130 Decibels when measured using A weighting [dB(A)] for certain activities such as concrete chipping and grinding. In comparative terms, this is well above sustained human tolerance levels, and is on a par with an air raid siren in full operation. Demolition, in general, is one of the most noise intensive of all common activities, but oddly is essentially unregulated at the present time. The National Building Code, Ontario Health and Safety Act, United States Health and Safety Act, and Provincial and Federal Environmental Protection Acts, do not explicitly address the issue of construction noise. Vehicle noise is addressed provincially by various vehicle and highway and traffic acts, but none are directed specifically at demolition activities.

Most municipalities require the proponent of a demolition project to obtain a permit to commence work and this application process typically involves the submission of a demolition plan. The demolition plan identifies noise abatement strategies and must demonstrate compliance with municipal by-laws which address noise concerns, if applicable.

A measure of emission control is provided by the various Vehicle Acts as the manufacturers of construction machinery are required to meet noise emission criteria, therefore individual machines are controlled to some degree. The United States Environmental Protection Agency requires all large vehicle (greater than 10,000 lb) interior noise be limited to 90 dB(A) and emitted noise to be below 80 dB(A). A large proportion of construction equipment is manufactured in the United States and
thus complies with this standard, which is referenced in the Federal Motor Vehicle Safety Standards (FMVSS).

The impact of using multiple pieces of equipment (as in demolition) is a non-linear increase in noise level for a given task, as more machinery is utilized. Additionally, average noise levels from ICI construction activities fluctuate widely and this fluctuation is in itself a source of annoyance. To account for both steady state and fluctuating noise levels, an index known as Noise Pollution Level (NPL) is utilized. The NPL for the heavy construction phases of an office building construction project varies from 85 dB to 107 dB, with most tasks being close to 100 dB. The NPL data cited was measured at a distance of 15 m to the noisiest piece of equipment and 61 m to the most distant, thus simulating the level of impact on passerby. Although data specific to a demolition site was unavailable, the upper ranges of the ICI data provide a conservative estimate of demolition noise levels, particularly those involved with concrete recycling and reuse. Steel and wood recycling would be slightly quieter, and steel and wood reuse, would be comparatively unobtrusive since less heavy machinery is utilized.

The consequence of the foregoing NPL levels can be defined by the following ranges excerpted from a study commissioned by the USEPA:

**NPL between 74 dB and 88 dB - Normally Unacceptable**

"The noise exposure is significantly more severe so that unusual and costly building constructions are necessary to ensure some tranquility indoors, and barriers must be erected between the site and prominent noise sources to make the outdoor environment tolerable."

**NPL greater than 88 dB - Clearly Unacceptable**

"The noise exposure at the site is so severe that the construction costs to make the indoor environment acceptable would be prohibitive and the outdoor environment would still be intolerable."

Despite the above, the use of coordinated noise abatement on demolition sites is rare. In very dense urban areas or when blasting is utilized, noise barriers are sometimes erected. In most cases however, the erection of plywood fencing as per Section 8.2.1.3 of NBCC 1995 is the only measure undertaken.

A high level of protest by adjacent property owners and passerby is often mitigated by the following factors/perceptions:

- perceived duration of demolition activity is short therefore a higher level of
annoyance is tolerated;

- demolition only occurs once and hence the activity is not repeated or sustained, again leading to increased tolerance;

- the objections are only voiced after project commencement, at which time it becomes clear that the original proposed strategy is insufficient. Additional abatement strategies are not contractual obligations once the contract is awarded and commences, and thus, will cost extra;

- dense urban areas often have very high ambient noise levels of 70 dB(A) or more, versus 50 dB(A) in quieter residential areas. The high ambient levels diminish the relative impact of demolition activities in urban areas.

Effective, fixed sound attenuating panels exist, but are expensive and are typically used only in permanent or semi permanent applications. Large, heavy civil projects such as road extensions utilize these devices, but application on other construction sites is rare.

4.3.2 Future Trends and Impacts

The noise emission levels of individual pieces of demolition machinery will undoubtedly decrease in the future. This reason for this, is that most noise emanates from various individual components, all of which, have historically become increasingly quieter. The use of turbochargers on diesel truck engines for example, has resulted in noise level reductions of approximately 5 dB(A) over the past several decades.\(^*\) The combination of improved tire designs, engine enclosure insulation, transmission designs and exhaust systems, will likely result in significant additional noise reductions over time.

Additionally, significant amounts of excessive noise can be accounted for by degradation in equipment performance due to poor maintenance. This trend will likely reverse as material scarcity drives the cost of new equipment up, and hence initiates higher maintenance standards. Increased instrumentation technology will also facilitate easier and more widespread legislative enforcement.

Due to the anticipated escalation in cost, of both fuel and manufactured items, as well as the possibility of a "full cost accounting" taxation measure to deter non essential fuel consumption, the future use of motorized vehicles will likely decline substantially. The impact of this will be a reduction in urban ambient noise levels at the end of the test case building life cycles, since most ambient noise originates from motor vehicles and other fossil fuelled machines. Additionally, the scarcity of fuel and subsequent decrease in the practice of commuting will likely result in higher urban population
densities. The extrapolated impact will be less tolerance for high NPL demolition activities and possibly a more restrictive legislative environment.

The anticipated specific effects on the demolition process are summarized as follows:

- the use of engineered noise barriers will become much more prevalent;
- high noise processes will be modified to be scheduled coincidentally with periods of high ambient noise;
- quieter forms of equipment will be utilized (i.e., hydraulic versus pneumatic);
- work will be scheduled to maintain a constant noise level, thereby reducing the NPL;
- custom mufflers and other types of noise baffle may be developed to augment existing factory installations;
- the viability of quieter forms of demolition will increase (i.e., reuse versus recycling).

It is difficult to assess the relative impact in energy terms of the above, since some activities will reduce demolition process energy consumption (i.e., scheduling uniform equipment run cycles) and some will increase energy consumption (i.e., erection of noise attenuation systems). A further, more detailed analysis would be required to establish the impact in quantitative terms.

### 4.4 DUST CONTROL

The issue of dust during demolition is similar to that for noise, in that large quantities are generated by the industry, but little is done to prevent or mitigate it. Also similar is the lack of prescriptive legislation to limit or control dust from demolition activities. The OHS, NBCC 1995, CEPA, and Ontario EPA only reference dust obliquely and the US OSHA makes a brief reference to the requirement for dust reduction during excavation, but qualifies the requirement by the prefix "... if possible...".

Fortunately, dust is less of a problem than noise because there is a direct benefit to the contractor to minimize dust, especially when machines are used. Dusty conditions cause air filter clogging, excessive fuel consumption, and shorten the lifespan of mechanical components, resulting in increased cost to the contractor. This notwithstanding, the use of dust control is not as common as one might expect. This is
due to the technical difficulty in implementing effective measures in a demolition setting. Only three measures are commonly employed as follows:

1. Water Spraying - Tanker trucks equipped with spray bars and hoses periodically wet the offending surfaces, thereby suppressing dust generation;

2. Chemical or oil application - Calcium Chloride, the most common dust suppressant, is sprayed on to the dust generating surface either in the form of a 35% waterborne solution or in the form of dry flakes. Oil is sometimes used, but typically only in semi permanent applications such as access roads and parking lots;

3. Dust Barricades and partitions - These are usually wood frame walls constructed of 25mm X 76mm lumber with 0.2mm polyethylene sheeting. The walls are placed to segregate work areas and prevent dust migration.

The feasibility of using any of the above on a structural demolition project is dependant on the individual circumstances, but all are usually specified for specific applications such as use on horizontal surfaces located on grade.

The use of water is limited by the difficulty of application and by the unpleasant (and possibly unsafe) work conditions caused by water accumulation and mud creation. It would be very difficult to effectively "wet down" a three storey office building without installing a system of pipes and nozzles, and such a system would likely interfere with the demolition work itself. Water could be used for site activities, excavation of footings and for suppressing dust during crushing, however.

Similarly, chemicals and oil would be virtually impossible to apply to the upright structure, but could be used to treat the site and the stockpiling and crushing area.

Dust partitions are frequently used for segregating demolition activities from the balance of occupied buildings but would have to be moved continuously during demolition of an entire structure and it would be difficult to stop fugitive emissions. Enclosing a three storey building, although done occasionally during asbestos abatement, would not be practical for demolition. It may be possible to enclose smaller areas such as the crusher during concrete processing but this would likely lead to productivity problems and possible dust damage to equipment unless powered air filtration was utilized. Demolition occurring adjacent to other structures or in dense urban areas sometimes uses nylon mesh debris screens which enclose the building. These screens provide some mitigation of dust emissions but are not completely impermeable.

Based on the above, it is clearly difficult to draw any conclusions regarding energy
impacts for this activity. Due to the aforementioned technical difficulties and impossibility of projecting future technologies, the dust control issue is duly noted, but at this point no further consideration is recommended.

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7. Ibid.

5.0 FUEL AND ENERGY CONSUMPTION

5.1 GENERAL

The demolition machine energy estimates in Section 7.0 were performed by summation of the individual machine run times for a particular task multiplied by their respective estimated fuel consumption rates. Application of the fuel content factors contained in the ATHENA™ research guidelines yielded energy expenditures applicable to a given task.

The accuracy (in absolute terms) of the above energy estimates is dependant upon realistic energy consumption rates. Unfortunately, dynamic fuel consumption data for construction equipment is scarce. To effect the required energy calculations, consumption estimates based on a combination of theoretical data and field observations were therefore utilized.

It was recognized that energy expended by humans did contribute to the overall demolition energy and a model was developed to compute the value of this expenditure. It was determined, however, that the relative magnitude of human energy is negligible since average construction worker energy output is only 0.9 MJ/hour.1 Human energy was therefore excluded from the energy factors applied to the case studies.

5.2 DEMOLITION MACHINE FUEL CONSUMPTION

As noted, actual empirical data for fuel consumption is difficult to obtain. Interviews with several manufacturers/distributers indicated the following as probable causes for the lack of published data:

- Manufactures are reticent to commit to specific fuel consumption rates due to wide variability in usage patterns and the resultant lack of reproducibility;

- Project conditions such as site grading, density of materials, structural resistance (in the case of demolition), soil conditions, operator style, weather, altitude, etc., all have a significant influence on fuel consumption;

- Considerable disparity exists in equipment age, condition and maintenance patterns, all of which impinge on fuel consumption;

- The usage patterns and type of mechanical/hydraulic attachments varies with the type of project and has a considerable impact on actual fuel consumption;
Total fuel consumption is a combination of run time plus idle time. The ratio of actual use to idle is highly project (and even task) specific and is difficult to generalize.

Steady state fuel consumption based on engine/machine bench testing or sample work trials, is available in manufacturers' reference documents such as the Caterpillar Performance Handbook and in individual equipment performance specifications. Steady state estimates are based on Brake Specific Fuel Consumption (BSFC) obtained by running machines against static resistance over a range of engine speeds and recording the respective fuel consumption rate. Work trial data is obtained by performing sample tasks with several typical use patterns.

Interviews conducted by Maple Engineering with several subcontractors and owner operators indicated that the work trial data was a reasonable starting point for actual estimates.

Several theoretical estimates of consumption were attempted based on specific engine outputs and known thermodynamic efficiencies, but inconsistent results were obtained and a poor correlation to contractor observations was noted. The trial data estimates, modified for contractor observations, were thus used for all computations. A 5% multiplier was applied to all base consumption estimates to reflect the fact that most machinery is several years old and runs at less than optimum efficiency. Similarly, contractor interviews indicated that winter operation resulted in approximately 10% greater fuel consumption for the same machinery. A winter multiplier of 10% over the modified estimates was used for all winter fuel consumption rates.

The trial data fuel estimates were all based on continuous machine operation at "heavy intensity." No idle time was accounted for in the computations. This assumption is simplistic in current terms, since long periods of machine idling are very common on typical construction sites. This is due to a variety of factors, including machines waiting for completion of subordinate tasks performed by humans or other machines. It was assumed that future practices would limit this activity due to higher fuel costs as per Section 3.1.

Table 5.2 summarizes the results of the fuel consumption estimates. The fuel consumption rates noted in the table were used for all of the case study energy estimates in summarized Section 7.0.
<table>
<thead>
<tr>
<th>Machine Type</th>
<th>Activity / Attachment</th>
<th>Fuel Consumption (L/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caterpillar 325L</td>
<td>Concrete breaking - Hammer</td>
<td>28.3 D</td>
</tr>
<tr>
<td>Caterpillar 325L</td>
<td>Concrete loading - Bucket</td>
<td>25.2 D</td>
</tr>
<tr>
<td>Caterpillar 325L</td>
<td>Excavation - Bucket</td>
<td>22.1 D</td>
</tr>
<tr>
<td>Caterpillar 325L</td>
<td>Wood dismantling - Grapple</td>
<td>25.2 D</td>
</tr>
<tr>
<td>Caterpillar 325L</td>
<td>Concrete crushing - Crusher jaws</td>
<td>28.3 D</td>
</tr>
<tr>
<td>Caterpillar 325L</td>
<td>Steel dismantling &amp; prep. - Shear</td>
<td>28.3 D</td>
</tr>
<tr>
<td>Caterpillar 426B</td>
<td>Crushed concrete loading</td>
<td>16.8 D</td>
</tr>
<tr>
<td>Tridem dump truck</td>
<td>Materials transport</td>
<td>24.1 D</td>
</tr>
<tr>
<td>Truck mounted crane</td>
<td>Wood and steel handling</td>
<td>20.0 D</td>
</tr>
<tr>
<td>Self propelled crane</td>
<td>Steel handling</td>
<td>18.9 D</td>
</tr>
<tr>
<td>Forklift</td>
<td>Material loading</td>
<td>12.6 D</td>
</tr>
<tr>
<td>Thomas skid steer</td>
<td>Chipped concrete site transport</td>
<td>5.2 D</td>
</tr>
<tr>
<td>Atlas XAS compressor</td>
<td>Compressed air for pneumatic tools</td>
<td>10.1 D</td>
</tr>
<tr>
<td>Tractor trailer truck</td>
<td>Material and equipment transport</td>
<td>24.1 D</td>
</tr>
<tr>
<td>Innovator tub grinder</td>
<td>Wood chipping</td>
<td>32.5 D</td>
</tr>
<tr>
<td>Nordberg city crusher</td>
<td>Concrete crushing</td>
<td>13.6 D</td>
</tr>
<tr>
<td>Skil quick-cut saw</td>
<td>Reinforcing steel cutting</td>
<td>3.1 G</td>
</tr>
<tr>
<td>Pick up truck</td>
<td>Site supervision</td>
<td>9.4 G</td>
</tr>
</tbody>
</table>

*Table 5.2. Fuel consumption for test case demolition machinery*

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6.0 PRODUCTIVITY FACTORS

6.1 GENERAL

The demolition energy analysis undertaken in this study was performed by quantification of site energy expenditures, and likewise the raw energy data identified in Section 7.0 and the appendices is primarily derived from run times of machinery and labour. Productivity factors directly affect both labour estimates and to some extent machinery run times and therefore an examination of some of the more significant productivity factors was performed and their expected impact on energy use incorporated into the energy expenditure calculations.

Construction productivity is most accurately measured by observing the number of units produced (or demolished) per person hour consumed.\(^1\) Since demolition involves removal of a structure, the reciprocal measure of person hours consumed per unit demolished is more appropriate. Applicable productivity factors are those which directly or indirectly affect the number of person hours required to effect demolition of a given unit of structure. As noted in Section 3.0, machine use is an integral component to most demolition processes and is closely tied to manpower allocation. Increases in manpower requirements will therefore increase the run time of machinery and vice versa.

Productivity in the demolition sense can thus be defined as:

\[ \text{The rate of structure demolition/deconstruction as a function of machine and labour intensity.} \]

As noted in Section 1.0, the construction (and demolition) industry is large, complex and influenced by a multitude of factors both internal and external. By corollary, construction and demolition productivity is subject to multiple influences, many of which are difficult or impossible to quantify. The Canada Construction Industry Development Council (CIDC) identifies seven general categories of influences which have the potential to seriously impair construction productivity and notes 95 specific factors.\(^2\) Table 6.1 identifies the more significant of these factors within each category.

All of the categories and factors identified in Table 6.1 are project and time specific and are somewhat unpredictable. The baseline machine and labour time take-offs summarized in Section 7.0 and the appendices, are based on ideal conditions and the internal practices of a large, comparatively sophisticated contractor. As a result, the internal productivity factors identified in Table 6.1 have, in essence, been incorporated
directly into the take-off computations for normal operating conditions

The external factors identified are very project and time specific, and fluctuate widely with changes in economic and political trends. Both of the test locations (Vancouver and Toronto) are large urban centres subject to similar external drivers. Given this, and given the impossibility of generalizing project level peculiarities, external factors have been excluded from further analytical consideration. The exception to this is the Project Condition category which is examined in greater detail in Section 6.2.

<table>
<thead>
<tr>
<th>Category</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Conditions</td>
<td>- Weather variability (external)</td>
</tr>
<tr>
<td>Market Conditions</td>
<td>- Material shortages (external)</td>
</tr>
<tr>
<td></td>
<td>- Lack of experienced design and project management personnel (external)</td>
</tr>
<tr>
<td>Design and Procurement</td>
<td>- Large number of changes (external)</td>
</tr>
<tr>
<td>Construction Management</td>
<td>- Ineffective communications (internal)</td>
</tr>
<tr>
<td></td>
<td>- Inadequate planning and scheduling (internal)</td>
</tr>
<tr>
<td></td>
<td>- Lack of sufficient supervisory training (internal)</td>
</tr>
<tr>
<td>Labour</td>
<td>- Restrictive union rules (external)</td>
</tr>
<tr>
<td>Government Policy</td>
<td>- Slow approvals and issue of permits (external)</td>
</tr>
<tr>
<td>Education and Training</td>
<td>- Lack of management training for supervision, project management (internal)</td>
</tr>
</tbody>
</table>

Table 6.1 Factors Seriously Impairing Construction Productivity (after CIDC 1984).³

6.2 PROJECT CONDITION FACTORS

Project condition factors are examined in this section to determine whether a significant difference in productivity can be anticipated for each of the baseline test cases identified in Section 3.0, in the different test locations (Vancouver and Toronto).

Interviews with contractors and review of the R.S. Means database indicate that raw productivity of workers in both locations is similar and is difficult to compare in general terms. Economic factors do vary considerably, however, and often dictate the specific approach taken for demolition, since cost is still the primary controlling driver
in selection of an applicable demolition strategy.

As an example, McColman and Sons Demolition (Edmonton, Alberta) indicated that wood recycling has a very limited appeal in Western Canada due to liability concerns surrounding residual metals (nails, hangers, etc.) which are not removed during processing by electromagnetic screening. Use of the processed wood by pulp mills and by hog fuel consumers is contingent upon effective removal of all residual metal to minimize the risk of process machinery damage. To ensure complete removal, increased labour is required to de-nail prior to processing which effectively eliminates any economic advantage of recycling.

The approach taken in this study, to determine the case specific demolition energies, was to develop a representative baseline approach and then apply modifiers to fine tune the estimates for each location. Because the demolition process is unregulated and contractor preferences and styles vary considerably, only a single composite methodology was used. The productivity factors incorporated as modifiers, are those applicable to the baseline methodology only, rather than those influencing a particular contractor. Most of the following project conditions are therefore not directly applicable in a quantitative sense since they are contractor specific. In the composite methodology, the same contractor is, in a sense, performing all of the case studies in each location. The examination of the various influences is useful nonetheless, to place the developed standard methodology in a realistic, contracting context.

6.2.1 Site Set-Up and Layout

Demolition, like construction, is comprised of a series of repetitive linked tasks which are often overlapped. The speed and efficiency of task throughput is a fundamental component of site productivity and much effort has been expended developing sophisticated productivity models based on task cycle times. Review of various simulation models as well as those based on site observations clearly point out the necessity for an organized, efficient workplace which encourages establishment of a production line type environment.

The literature identifies the development of patterns of increasing productivity with task repetition due to streamlining of the construction process over time. This phenomena is caused by progression along a "learning curve". A key prerequisite to the development of this pattern, is the creation of an environment where tasks are repeatable, and where continuous improvement can be effected, thereby causing an increase in productivity.

To facilitate the above, the demolition site should possess the following characteristics:

- Clearly delineated areas for staging, storage and production;
- Unimpeded access/egress for material delivery and waste production removal;
- Clearly marked and secure containers for source separated materials;
- Vehicle/equipment routes which are planned for maximum efficiency and which are actually used;
- Conveniently located sanitation facilities and a warm, dry site trailer;
- Central compressed air system with multiple connection points;
- Sufficient tools and equipment in good working order;
- Easily accessible POL area.

Additionally, the site should be formally organized, in advance, using a documented plan which is integrated with the demolition plan, fire response, and safety plans. The contents of the plan, site layout drawings, and procedures/regulations should be conveyed to all members of the project team prior to commencement and periodic update briefings held when required.

As noted previously, all of the above criteria are assumed to be met in the baseline methodology which is common to both locations. Demolition by a poorly organized contractor, or one lacking sufficient resources will result in decreased productivity and consequently higher demolition energy for all of the cases identified in Section 3.0.

### 6.2.2 Workplace Density and Scheduling

The methodology established in Section 3.0 is based on optimum scheduling of tasks with minimal disruption to work progress. A significant and predictable loss of productivity occurs, as schedules are compressed beyond optimum and increased numbers of workers and machines are brought to bear on the project.

Overstaffing results from assigning more workers than are required to perform a given task. Optimum crew size is the minimum number of workers required to complete a task economically, within a given time frame, and exceeding this number has a proportional, degrading effect upon productivity. Similarly, attempting to accelerate the construction schedule by bringing additional crews on site results in site crowding. Congestion on the site creates a hazardous work environment which is disorganized. In both cases, productivity reductions of up to 20% have been noted and this would correlate to proportionate increases in energy expenditures.
Compression of schedules by increasing the number of shifts and/or increasing the shift length will result in similar reductions in productivity. This occurs because of worker fatigue, increased numbers of errors or defective work which requires correction, pacing of work by the workers to accommodate the longer work day and accidents. The longer that extended hours are worked, the greater the impact of the productivity loss. As an example, after four weeks of continuous overtime, a crew will only produce the equivalent of 55 hours normal output even though they are working an 84 hour week. This is a direct reduction in productivity of over 30%.

In terms of C&D waste management, lack of sufficient time to perform source separation and site preparation of materials (i.e. de-nailing, deconstruction, etc.) is a significant factor in reduced landfill diversion rates. Sloppy deconstruction techniques or their complete absence, will result in a sharp decrease in the reusability of most building components. Similarly, cross contamination of source separated materials destined for MRF’s will result in increased tipping fees and possible rejection. Both are far more likely to occur under an accelerated schedule due to the time required for selective demolition or deconstruction. Removal of individual building components, intact and without damage, requires approximately 50% of the time needed for original installation. Most demolition projects, however, are specified for completion in less than 10% of the time which was provided for original construction.

The schedules proposed in Section 3.0 for all of the case studies, are based on actual 3R requirements, and have allotted ample time to perform the selective demolition and deconstruction required to achieve the 100% reuse and recycling objectives cited.

### 6.2.3 Site Servicing

This item is closely related to site set-up (Section 6.2.1) and is an essential part of the support required to maintain continuous production (demolition) output. In the specific case of structural demolition, compressed air and electrical power (from temporary panels) are essential services to maintain a smooth, uninterrupted progression of work.

Section 8.2.2.9 of NBCC 1995 specifies the disconnection and capping of all building services prior to demolition. Temporary installations for water (required for cleaning and dust control), electricity (temporary lighting and tools), gas (heating) as well as sanitary and storm water systems must be installed, if required. Temporary service systems must be planned in advance of work commencement, and must be designed to be flexible, easily set-up and moved, if required, and must be suited for the load and application. Inadequate electrical installation systems which lack capacity, sufficient outlets, or proper grounding/insulation will have a significant, detrimental impact on productivity, but unfortunately, are a common occurrence due to poor planning.
Hoarding and temporary heating is uncommon on demolition projects with the exception of selective demolition or small projects occurring in parts of occupied buildings. Projects involving entire removal of structures, as is the case in this study, do not usually utilize temporary heating due to the risk of damaging the heating systems during removal operations and the obvious risk of fire.

The estimates in Section 7.0 assume a well planned and serviced site layout which does not impede work progress.

6.2.4 Safety and Work Interruption

The construction industry regularly suffers significant monetary and productivity losses as a result of job site accidents. In monetary terms, accident costs have been estimated at over 6.5% of total yearly construction cost in the United States. Productivity losses due to accidents are not readily quantified but are nonetheless significant. Accidents result in temporary work stoppage and may initiate protracted periods of idleness while investigations are conducted and the cause of the accident (if site related) is identified and corrected. Secondary impacts to the balance of the workers may include demoralization, depression and slow progress due to over caution.

Most accidents occur due to poor worker training, lack of skills, or sloppy job site conditions. All of these are easily avoided by professional internal management practices. Demolition is inherently hazardous and requires an even greater emphasis on formalized safety procedures than normal construction.

Productivity is adversely affected by equipment failure in a similar fashion to that noted for accidents. Frequent work stoppages result in a gross work slowdown which exceeds the accumulated actual stop time. The break in rhythm which occurs causes interruption of the learning curve and may require up to 40% additional labour input to overcome.

The take-offs in Section 7.0 are based on a safe work site using trained personnel. Accident downtime is not included in the computations. The equipment productivity rates utilized are similarly based on normal maintenance interruptions (fuel, lubrication, and routine repairs) and assume equipment is in good working order.

In energy terms, work interruption stemming from either accidents or equipment failure will result in increased expenditures. This is a result of the decreased overall productivity which is experienced and the consequent additional machine and labour time required to compensate. As with the previous cases, undertaking the proposed case studies with an unprofessional, inexperienced, or poorly equipped contractor, will result in higher demolition energies than those estimated.
6.2.5 Environmental Conditions

It is universally accepted in the construction industry that adverse environmental conditions result in a reduction in productivity.\textsuperscript{14} Ideal environmental conditions are dry, free of dust, atmospheric pollutants, and noise, and possess a temperature between 10°C and 21°C with relative humidity (R.H.) of 30% to 80%. Conditions falling outside of these parameters have degrading effects on productivity, health and safety.\textsuperscript{15}

Noise is discussed in detail in Section 4.3 and although very high levels are common in all aspects of demolition, the productivity impact can be effectively mitigated by use of protective equipment. The take-offs assume that all workers are equipped with appropriate ear protection as per the Ontario Health and Safety Act and thus productivity modifiers for noise were not developed.

Air quality factors were also not developed for two reasons. The first is that both Vancouver and Toronto are dense urban centres and hence experience similar air quality conditions. Since the take-offs in Section 7.0 are based on empirical urban databases, the effect of reduced air quality is already accounted for, to some extent. Secondly, air quality at any given time is difficult to predict and empirical studies demonstrating quantitative effects do not exist.

The impact of poor weather, on the other hand, is fairly well documented.

Adverse weather affects construction activities in five basic categories as follows.\textsuperscript{16}

(i) Complete job shutdown during which bad weather temporarily prevents work from progressing.

(ii) Reduced productivity which occurs when work is continued during bad weather but at a lower output rate.

(iii) Repeat work required to correct damage caused directly by poor weather or to correct deficient work which occurred indirectly as a result of adverse conditions.

(iv) Downtime which occurs when workers are absent, late or dismissed early as a result of bad weather.

(v) Compressed schedules or shortened work weeks that result due to poor weather and contribute to a loss of project momentum.

Item (ii), productivity loss, can be estimated with some measure of accuracy since it is controlled by two easily measured variables, temperature and relative humidity (R.H.). The other categories, although accounting for greater total man-hour losses, are very
difficult to quantify and no generally applicable models were found in the literature.

The impact of weather upon construction productivity has been intensely studied and several empirical models exist for estimating the effects of temperature and humidity upon productivity.

To develop modifiers for the thermal regimes in the two test locations, a literature review was conducted and two suitable models were selected for use on the climatic data in both locations.

The mean summer high and winter low temperatures and R.H. levels for both locations determined by Environment Canada are shown in Columns 2 to 4 in Table 6.2.3. Additionally, the January and July 2.5% dry bulb design temperatures as stipulated by NBCC 1995 are included to identify the worst case condition.

The two models applied to the climatic data in Table 6.2.3 are as follows:

.1 Koehn & Brown (1985)

This model is based on historical productivity data collected by investigating 172 data points in seven categories of construction trade. The data was derived from multiple sources and covers a range of -40°C at 10% R.H. to 52°C at 10% R.H.

.2 Thomas & Yiakoumis (1987)

This model is based on the development of performance ratios which compare the daily deviation of actual productivity to idealized productivity curves. The idealized curves were adjusted for productivity improvement due to the learning curve effect. This model was developed by analysis of 78 data points and covers a range from -11°C at 47% R.H. to 27.8°C at 32% R.H.
<table>
<thead>
<tr>
<th>Location</th>
<th>Data Point</th>
<th>Temp (°C)</th>
<th>R.H (%)</th>
<th>Productivity (Koehn &amp; Brown)</th>
<th>Productivity (Thomas &amp; Yiakoumis)</th>
<th>Mean P 0.5(5 + 6)</th>
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</thead>
<tbody>
<tr>
<td>Vancouver</td>
<td>August</td>
<td>21.7</td>
<td>63</td>
<td>0.87</td>
<td>0.90</td>
<td>0.88</td>
</tr>
<tr>
<td>Vancouver</td>
<td>July (2.5%)</td>
<td>26</td>
<td>62</td>
<td>0.88</td>
<td>0.83</td>
<td>0.85</td>
</tr>
<tr>
<td>Vancouver</td>
<td>January</td>
<td>0.1</td>
<td>81</td>
<td>0.46</td>
<td>0.72</td>
<td>0.59</td>
</tr>
<tr>
<td>Vancouver</td>
<td>January (2.5%)</td>
<td>-7.0</td>
<td>81</td>
<td>0.39</td>
<td>0.46</td>
<td>0.42</td>
</tr>
<tr>
<td>Toronto</td>
<td>July</td>
<td>26.5</td>
<td>53</td>
<td>0.88</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>Toronto</td>
<td>July (2.5%)</td>
<td>31</td>
<td>53</td>
<td>0.83</td>
<td>0.72</td>
<td>0.77</td>
</tr>
<tr>
<td>Toronto</td>
<td>January</td>
<td>-7.9</td>
<td>75</td>
<td>0.42</td>
<td>0.45</td>
<td>0.43</td>
</tr>
<tr>
<td>Toronto</td>
<td>January (2.5%)</td>
<td>-18</td>
<td>75</td>
<td>0.24</td>
<td>N/A</td>
<td>0.24</td>
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</tbody>
</table>

Table 6.2.2 Location Climatic Data and Associated Productivity Factors

The mean productivity factor (Column 7) was used to adjust the take-offs in Section 7.0 in accordance with Table 6.2.3. All summer activities were affected by the summer productivity adjustment because demolition machinery is generally not air conditioned. The result is a degrading productivity impact upon the equipment operators which in turn affects the machine run time.

Winter productivity factors only affect the manual labourers since all heavy machinery is equipped with heating systems. The exception to this is the concrete removal operations which involved chipping and reinforcement cutting. The small pieces of equipment used for these activities are not equipped with heating systems and their operators are therefore negatively influenced by cold weather.

The productivity factors were applied by multiplying the duration of the affected task by the inverse of the mean productivity factor shown in Column 7 of Table 6.2.2. This is a slight simplification since the tasks identified in Section 3.0 are not discrete, but nonetheless yields a reasonable starting point for further study.
<table>
<thead>
<tr>
<th>Case Study</th>
<th>Winter Conditions</th>
<th>Summer Conditions</th>
<th>Affected Task</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood Structure - Recycle</td>
<td>Concrete Topping Removal</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Reinforcing Cutting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood Structure - Reuse</td>
<td>Concrete Topping Removal</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Reinforcing Cutting</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>All Above Grade Work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Structure - Recycle</td>
<td>Concrete Topping Removal</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Reinforcing Cutting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel Structure - Reuse</td>
<td>Concrete Topping Removal</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Reinforcing Cutting</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>All Above Work Grade</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Structure - Recycle</td>
<td>Reinforcing Cutting</td>
<td></td>
<td>All</td>
</tr>
<tr>
<td>Concrete Structure - Reuse</td>
<td>None</td>
<td></td>
<td>All</td>
</tr>
</tbody>
</table>

Table 6.2.3 Tasks Affected by Summer and Winter Productivity Modifiers

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8. Ibid. p.19.

10 Ibid.

11 Productivity in Construction, op. cit. p. 25.


15 Productivity in Construction, op. cit. p. 23.

7.0 CONCLUSIONS

7.1 GENERAL

The results of the demolition energy computations are summarized in Appendix A and the baseline take-offs, complete with energy calculations, are contained in Appendix B.

The computed demolition energy ranged from a low of 91.71 MJ/m² for the wood assembly, baseline reuse case, in Vancouver, to a high of 890.67 MJ/m² for the structural steel assembly, reuse case, during extreme winter conditions (January 2.5%) in Toronto.

In terms of energy relative to mass of structure; the lowest computed energy was 0.107 MJ/kg for the concrete recycling baseline case, in Vancouver, and the highest was 2.43 MJ/kg, again for the structural steel reuse, Toronto extreme weather case.

The energy to mass results have been included for information purposes, but will not be used as a comparative indices because of the large variation in mass of the studied structural assemblies. It was felt that energy per unit of floor area, was a more comparative indices since the gross building area remains constant at 4620 m² in all of the study cases.

The wide variation in energy results is diminished somewhat if the extreme cold and hot weather conditions are excluded. The majority of actual projects, assuming year round project activity, would likely be close to the baseline estimates. These energy estimates ranged from a low of 91.71 MJ/m² for the wood assembly reuse case to a high of 222.9 MJ/m² for the steel assembly reuse case. The comparative baseline energy computation results are shown in Figure 7.1.
Figure 7.1 Baseline Demolition Energy
Recycling versus Reuse

The computed data yield the following general conclusions:

- The energy required for demolition of the structural system is small relative to overall life cycle energy, but significant relative to the initial embodied energy which was identified in the previous *Life Cycle Energy Use in Office Buildings* report. The relative difference between demolition energy and initial embodied energy is shown in Figure 7.1a;

- The demolition energy for steel structures is generally higher than that required for wood assemblies because of the additional machine time needed to handle the heavy steel members. Concrete structures actually require less energy to demolish than steel because the process is quick and efficient and requires comparatively less machine time;

- Demolition for reuse requires more energy than demolition for recycling with the exception of the low density wood structures. The reason for the higher reuse energies is because of the prevalent use of machines to augment manual labour, and because of the longer time frame required for deconstruction.
In the case of wood reuse, very little machine time was allocated to the above grade structural demolition, yielding a lower total demolition energy value;

- Demolition activities requiring large components of manpower are very sensitive to weather and incur significant energy penalties when performed under adverse environmental conditions;
- Demolition performed predominantly by large machinery is less affected by weather and is also less energy intensive due to high efficiency.

**Figure 7.1a Relative Energy Comparison**

Recycling/Reuse versus Embodied

7.2 **DEMOLITION ENERGY REQUIRED FOR RECYCLING**

The demolition energies computed for the three assembly types, in the two test locations, are summarized in Figure 7.2. The summer and winter scenarios (represented by S and W in Figure 7.2) are for the July/August and January productivity factors developed in Table 6.2.2. A brief description of each assembly result is provided below.
7.2.1 Wood Assembly

The baseline result for this energy computation was 118.33 MJ/m² which was actually higher than that computed for the steel and concrete assemblies. This is primarily the result of the construction detailing and design parameters used in the studied structure. The presence of shear walls, multiple framing members, and large laminated beams, slows down the demolition process and requires considerable energy to reduce the members to fragments suitable for on-site chipping. Laminated beams and columns are much more difficult to break into smaller pieces (using site machinery) than traditional, sawn lumber members.

The wood recycling operation was quite sensitive to the productivity factors because of the extensive use of manual labour (augmented by machines) for the removal of the concrete floor toppings. This operation was performed by manually separating the concrete from the plywood sheathing using pneumatic chipping hammers. The topping removal operation accounted for 21.5% of the total demolition energy for this case and was sensitive to weather because all facets were performed under exposed conditions.
7.2.2 Steel Assembly

The steel recycling case had a comparatively low baseline energy of 110.3 MJ/m². The overall demolition process was quick and efficient but, similar to the wood recycling case, was very sensitive to adverse weather conditions. The Toronto winter case was almost twice as energy intensive (217.52 MJ/m²) as the baseline case, again due to the large energy allocation attributed to the floor topping removals.

7.2.3 Concrete Assembly

Despite the very high mass of the concrete frame and its monolithic construction, the demolition process was found to be relatively energy efficient. The baseline energy value was 103.44 MJ/m² and the process was not affected by adverse weather as much as the other assembly types. The winter and summer energy values rose by approximately 25% (maximum) over the baseline case. The exclusive use of large, heavy demolition machinery made the process weather independent during winter with the exception of the reinforcement cutting. The summer case was affected for all tasks but the impact was mitigated by the lower productivity factors applied for summer conditions.

7.3 DEMOLITION ENERGY REQUIRED FOR REUSE

Figure 7.3 summarizes the demolition energy for the reuse scenarios described in Section 3.3, in each of the locations, and in the respective summer and winter scenarios.

As noted in 7.1, the reuse energy values are generally higher than those noted for recycling and are very sensitive to extraneous factors such as weather. A much larger energy differential was observed between assembly types particularly in the case of the steel structure. This disparity is a function of the significant methodological difference between demolition (for recycling) and deconstruction (for reuse) and is indicative of a rather poor integration between machine and manual labour components.

A brief description of the results of each case are provided in the following subsections.
7.3.1 Wood Assembly

As noted previously, the wood reuse baseline energy value was the lowest of all of the values determined at 91.71 MJ/m². This is due to the almost exclusive use of manual labour for all of the above grade dismantling work. The heavy reliance upon manual labour makes the process susceptible to adverse weather, however, and this is reflected in the elevated winter and summer energy values in both locations.

7.3.2 Steel Assembly

The results of the energy analysis for this case were surprising since they yielded the highest value of all of the examples studied. Intuitively, the deconstruction of a steel frame for reuse would seem to be prudent, in terms of energy consumption, especially since the process involves a large manual labour component. The case analysis revealed that the process is in fact very energy intensive due to the extensive use of cranes for hoisting and supporting the bearing members, and due to the requirement for multiple compressors, needed to power pneumatic ratchet drivers which were used for disassembly of the bolted connections.
The integration of manual labour and machines also makes the process extremely susceptible to environmental productivity factors, especially cold weather. The baseline energy value of 222.9 MJ/m² rose to 513.97 MJ/m² when factored for Toronto winter conditions.

7.3.3 Reinforced Concrete Assembly

The results of the energy computation for this case were very similar to that for the recycling case. The baseline energy value was computed to be 103.44 MJ/m². The process was found to be comparatively unaffected by environmental conditions with the exception of the summer cases. The Vancouver summer conditions resulted in an energy increase to 143.71 MJ/m².

The energy required for concrete reuse was slightly higher than that for recycling since 'on site' crushing was included in the energy estimates.

7.4 COMPARISON TO OTHER STUDIES

Very little published data was found which provided explicit, quantitative estimates for demolition energy. The baseline computed values for demolition energy determined in this study are slightly higher than those noted in the literature reviewed. The increased values are likely due to the more energy intensive demolition methodology modelled and due to the fact that ICI structural assemblies were used as test cases. Demolition and deconstruction, for recycling and reuse respectively, involve longer time frames, more equipment and additional on-site processing steps compared to standard machine demolition, especially that used for residential demolition.

7.5 ADDITIONAL OBSERVATIONS

A review of the demolition energy analysis results and the study methodology, in the context of the overall ATHENA™ project yields several additional observations.

The most significant of these, is the increase in demolition energy which would be observed if an entire building, including all interior systems, were analyzed. The increase in demolition energy would not be a linear function of increased building material mass. Because of the intricate nature of interior finishes and systems, an increase in energy of at least 100% could be anticipated for recycling demolition and an increase of several hundred percent to perhaps a full order of magnitude, could be
anticipated for reuse operations.

The high energy toll associated with reuse deconstruction is indicative of the level of integration which exists between manual labour and machine support. The deconstruction process could be far more energy efficient if longer project schedules (allowing exclusive use of manual labour) were feasible, and if labour costs were competitive with machine use costs. The "design for deconstruction" issue is central to the deconstruction energy discussion, since it is a significant contributing factor to the requirement for machines. As an example, the wood structure analyzed in this study was far more amenable to deconstruction because of the ease of connection removal and the lower weight of individual structural members, which minimized the requirements for machinery, however the extensive use of laminated members made recycling difficult.

Another observation was the confirmation that demolition is very project specific and that the sensitivity of a given project to external factors is tied to the methodology employed. Each of the case studies analyzed was comprised of a very specific sequence of steps and processes. Even small changes in methodology can have significant impacts on demolition energy, particularly during periods of inclement weather.

7.6 RECOMMENDATIONS FOR INCORPORATION OF RESULTS INTO ATHENA™

ATHENA™ is designed to provide quantitative analysis of various building assembly life cycle costs using actual design data. The model will allow designers to specify various building materials and configurations and in turn provide a detailed environmental profile of the specified assembly. While input parameter control is important in any design tool (to provide flexibility), it must be balanced against the risk of overcomplicating the user interface which could render the tool too onerous for practical, day to day, use.

In order to satisfy the above requirement, incorporation of the result of the demolition energy analysis into ATHENA™ will require the adoption of several simplifying assumptions. It was concluded in Section 7.5, that the demolition process is very project specific and that significant variability currently exists in methodology. Incorporation of these conclusions into ATHENA™, directly, would require inputs for all variables including specific details on demolition methodology, machine type, degree of deconstruction potential, location, etc.

Given the relatively small magnitude of demolition energy to overall life cycle energy,
and the difficulty in predicting specific demolition practices in the future, the following assumptions would allow initial incorporation of the demolition energy results into ATHENA™:

- Assume that demolition occurs during ideal environmental conditions. This assumption will allow use of the baseline energy results and negates the requirement for detailed schedule analysis to be performed (impossible for events occurring far in the future in any case);

- Assume that the wood structural system will be subject to a combination of recycling and reuse. A 50% recycling - 50% reuse split is a reasonable starting point to provide ATHENA™ with a basis to compute demolition energy;

- Assume that all cast in place concrete will be subject to crushing and reuse on site;

- Assume that steel structural assemblies are subject to a combination of recycling and reuse. It is suggested that all primary structural members with a section depth of 200 mm or greater be specified for reuse. The balance of the steel can be assumed to be cut and removed for recycling at an off site MRF.

Structural assemblies which are specifically designed for deconstruction would obviously require manual input of more applicable energy estimates to override the assumed default values. Similarly, environmental factors which can be realistically estimated should be entered, since very large energy fluctuations are observed with changes in weather.

As noted in Section 7.4, considerable difference between the ICI data developed in this study and residential demolition energy estimates is probable. In order to allow ATHENA™ to evaluate lighter structural systems it may be useful to allow a toggle between residential and ICI structural types in the working model. To facilitate input of actual data, it would therefore be necessary to develop specific demolition energy estimates similar to those developed in this study, for commonly used residential assembly types.

Further to Section 7.5, it is also clear that development of a much more detailed demolition energy database would be required if ATHENA™ is expanded to include non-structural building components. The project specificity issue is even more salient in the case of interior finishes/assemblies by virtue of the greater range of variation
which is observed for these components.

In summary the baseline demolition data developed in this study could provide a reasonable starting point to facilitate launch of the working ATHENA™ model. The ability to manually "fine tune" the input parameters and increase the level of detail should be entertained if absolute quantitative data for specific demolition activities is needed and if input data is available.

---

1Life-Cycle Energy Use in Office Buildings. (Prepared by The Environmental Research Group School of Architecture, UBC, for Forintek Canada Corp., 1994), Table 4
REFERENCES


CONTACT LIST

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Telephone: (403) 465-5152
Fax: (403) 979-4174

Try Recycling Inc.
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Arva, Ontario
N0M 1C0

Telephone: (519) 457-3953
Fax: (519) 457-1570

ReUze Building Centre
1210 Birchmount Road
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M1P 2C3

Telephone: (416) 750-4000
Fax: (416) 750-4343

Harkow Aggregates & Recycling Limited
99A Commissioners Street
Toronto, Ontario
M5A 1A6

Telephone: (416) 463-5946
Fax: (416) 463-7167
AIM Waste Management Inc.
29 Banbury Crescent
Grimsby, Ontario
L3M 4R8

Telephone: (905) 572-1842
Fax: (905) 945-6467

Dewar Insulations Limited
81 Granton Drive, Unit #3
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L4B 2N5

Telephone: (905) 886-8730
Fax: (905) 886-8706
PREFACE TO APPENDICES

The tables contained in the following appendices consist of summary tables (Appendix A) and detailed 'take off' tables (Appendix B).

The summary tables contain references to the individual case studies described in Section 3.0 of the report and provide overall energy values and energy expenditures under varying weather conditions.

The 'take off' tables contained in Appendix B contain the breakdown of each case study and the corresponding energy expenditures for all discrete constituent tasks. It is important to realize that some tasks in the case studies could not be broken down into individual assembly items due to the methodology modelled (which is based on actual field practice). An example of this is can be seen for the above grade components of the wood and steel recycling case studies. In both of these examples, the above grade structure was removed in large sections and therefore the tables in Appendix B only show a total machine time and energy consumption value. The blank areas of the tables are therefore indicative of a methodology which is not specific to individual assemblies rather than a lack of data.
| Location  | Climate Point | [Productivity] $^{-1}$ | Recycle Case |  | Reuse Case |  |
|-----------|---------------|------------------------|--------------|------------------------|------------------------|
| Vancouver | Baseline      | 1                      | 546895        | 0.419                  | 118.37                | 423698             | 0.324                 | 91.71                  |
| Vancouver | August        | 1.14                   | 623460        | 0.47                   | 134.95                | 483016             | 0.37                  | 104.55                 |
| Vancouver | July (2.5%)   | 1.18                   | 645336        | 0.494                  | 139.68                | 499964             | 0.383                 | 108.22                 |
| Vancouver | January       | 1.69                   | 743759        | 0.569                  | 160.99                | 626418             | 0.480                 | 135.59                 |
| Vancouver | January (2.5%)| 2.38                   | 885933        | 0.678                  | 191.76                | 786767             | 0.602                 | 170.29                 |
| Toronto   | Baseline      | 1                      | 546895        | 0.419                  | 118.37                | 423698             | 0.324                 | 91.71                  |
| Toronto   | July          | 1.19                   | 650805        | 0.498                  | 140.87                | 504291             | 0.386                 | 109.13                 |
| Toronto   | July (2.5%)   | 1.3                    | 710963        | 0.544                  | 153.89                | 550807             | 0.422                 | 119.22                 |
| Toronto   | January       | 2.32                   | 873570        | 0.669                  | 189.08                | 772824             | 0.592                 | 167.28                 |
| Toronto   | January (2.5%)| 4.17                   | 1254762       | 0.961                  | 271.59                | 1202747            | 0.921                 | 260.33                 |

Table A1: Summary of Demolition Energy Calculations - Wood Assembly
<table>
<thead>
<tr>
<th>Location</th>
<th>Climate Point</th>
<th>([\text{Productivity}]^{-1})</th>
<th>(\text{Total Energy (MJ)})</th>
<th>(\text{Energy Int. (MJ/kg)})</th>
<th>(\text{Energy Int. (MJ/m}^3))</th>
<th>(\text{Total Energy (MJ)})</th>
<th>(\text{Energy Int. (MJ/kg)})</th>
<th>(\text{Energy Int. (MJ/m}^3))</th>
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Table A2: Summary of Demolition Energy Calculations - Structural Steel Assembly
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Table A3: Summary of Demolition Energy Calculations - Reinforced Concrete Assembly
## Table B1: Wood Structure

### Baseline Recycle Case

### Concrete Breaking/Recycle Off Site

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<th>Attachment</th>
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<th>Labour</th>
<th>Hours</th>
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**Subtotal**

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### Below Grade Vertical

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<th>Attachment</th>
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<th>Fuel Type</th>
<th>Fuel Energy Content (MJ/L)</th>
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<th>Labour</th>
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**Concrete Stockpiling, Loading & Transportation to Offsite MRF (15" minus nominal size material)**

| 1198831 | Stockpiling 15" | 1199MT | Concrete | Cat 325L | Bucket | 25.2 | Diesel | 38.68 | 1 | 1 | 20.03 | 1 | 19524 | 0.0163 |
| 1198831 | Loading | 1199MT | Concrete | Cat 325L | Bucket | 25.2 | Diesel | 38.68 | 1 | 1 | 20.03 | 1 | 19524 | 0.0163 |
| 336000 | Excavate Footings | 280m³ | Soil | Cat 325L | Bucket | 22.1 | Diesel | 38.68 | 1 | 1 | 7.00 | 1 | 5983.8 | 0.0178 |
| 1198831 | Transportation | 1199MT | Concrete | Tridem | Dump Trucks | 24.1 | Diesel | 38.68 | 1 | 1 | 4 | 1 | 3728.8 | 0.0031 |
|         | Float Trailer | Equipment | Tractor | Trailer | 24.1 | Diesel | 38.68 | 1 | 1 | 10 | 1 | 9321.9 | N/A |

**Subtotal**

| 1198831 |           |           |           |           |           |           |           |           |           |           |           |           |           | 55092 | 0.043 |

**Wood Demolition Recycling Off Site**

**Above Grade Horizontal**

| Glulam 494x130 | 135.2m | Wood |           |           |           |           |           |           |           |           |           |           |           |
| Glulam 532x75 | 132.2m | Wood |           |           |           |           |           |           |           |           |           |           |           |
| Glulam 494x175 | 270.0m | Wood |           |           |           |           |           |           |           |           |           |           |           |
| Glulam 570x215 | 264.0m | Wood |           |           |           |           |           |           |           |           |           |           |           |

**Above Grade - Secondary**

<p>| TJI Roof Joists | 1747.5m | Wood |           |           |           |           |           |           |           |           |           |           |           |
| Bridging 36x69 | 430.20m | Wood |           |           |           |           |           |           |           |           |           |           |           |
| Web stiffeners 36x69 | 354.16m | Wood |           |           |           |           |           |           |           |           |           |           |           |
| TJI Floor Joists | 5865.0m | Wood |           |           |           |           |           |           |           |           |           |           |           |</p>
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## Grand Total

| 150327     |                                           |          |          |             |                     |                       |          |                           |          |        |       |                      |             | 549553              | 0.419          |

*NOTES*

Projected time frame to complete is 5 weeks
Concrete Topping Removal Crew - 2 compressors with 4 chipping hammers, 2 skid steer with operators plus abourer
Concrete Breaking and Removal - 2 Caterpillar 235L excavators plus attachments
Mass of concrete includes reinforcing steel unless otherwise noted
Above grade wood demolition energy includes energy required for demolition of miscellaneous metal components
### Table B2: Wood Structure
#### Baseline Reuse Case

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Subtotal

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Wood Dismantling/Reuse

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<td>Above Grade - Secondary</td>
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<td>Equipment</td>
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**NOTES**

Projected time frame to complete is 10 weeks
Wood Removal Crew - 10 Men disassembling, crane plus operator, forklift plus operator
Concrete Topping Removal Crew - 2 compressors with 4 chipping hammers, 2 skid steer with operator plus labourer
Concrete Breaking and Removal - 2 Caterpillar 236L excavators plus attachments
Concrete Crushing - Production Rate of 80MT an hour
Steel fastener collection & stockpiling performed manually
### Table B3: Steel Structure
#### Baseline Recycle Case

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<thead>
<tr>
<th>Mass (kg)</th>
<th>Component</th>
<th>Quantity</th>
<th>Material</th>
<th>Equipment</th>
<th>Attachment</th>
<th>Fuel Consumption (L/hr)</th>
<th>Fuel Type</th>
<th>Fuel Energy Content (MJ/L)</th>
<th>Machines</th>
<th>Labour</th>
<th>Hours</th>
<th>Productivity Factor</th>
<th>Energy (MJ)</th>
<th>Energy Int. (MJ/kg)</th>
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<td>24327</td>
<td>Wall Footings</td>
<td>10.20m³</td>
<td>Concrete</td>
<td>Cat 325L</td>
<td>Hammer</td>
<td>28.3</td>
<td>Diesel</td>
<td>38.68</td>
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<td>Hammer</td>
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<td>Diesel</td>
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<td>1</td>
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<td>1</td>
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<td>Hammer</td>
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<td>Diesel</td>
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<td>1</td>
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<td>Diesel</td>
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<td>Concrete</td>
<td>Atlas Copco XAS 90 Comp.</td>
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<td>Diesel</td>
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<td>2</td>
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<td>195626</td>
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<td>879180</td>
<td>Chippings</td>
<td>375.95m³</td>
<td>Concrete</td>
<td>Thomas Skid Steer</td>
<td>Bucket</td>
<td>5.2</td>
<td>Diesel</td>
<td>38.68</td>
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<td>2</td>
<td>250.63</td>
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<td>0.1147</td>
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<td>Skil</td>
<td>Quick Cut Saw</td>
<td>3.1</td>
<td>Gasoline</td>
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<td>87.36</td>
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**Subtotal**

| 1384735 |                     |          |          |           |            |                          |           |                            |          |        |       |                     |             |                     |

<p>| <strong>Below Grade Vertical</strong> |                    |          |          |           |            |                          |           |                            |          |        |       |                     |             |                     |
| 80943    | Basement Walls     | 33.67m³  | Concrete | Cat 325L | Hammer     | 28.3                     | Diesel    | 38.68                      | 1        | 1      | 4.32  | 1                   | 4728.9      | 0.0584              |
| 4574     | Columns Below Slab | 1.87m³   | Concrete | Cat 325L | Hammer     | 28.3                     | Diesel    | 38.68                      | 1        | 1      | .24   | 1                   | 262.71      | 0.0574              |
| 3049     | Pilasters Below Slab | 1.25m³  | Concrete | Cat 325L | Hammer     | 28.3                     | Diesel    | 38.68                      | 1        | 1      | .16   | 1                   | 175.14      | 0.0574              |
| 6765     | Elevator Pit/Walls | 2.86m³   | Concrete | Cat 325L | Hammer     | 28.3                     | Diesel    | 38.68                      | 1        | 1      | .55   | 1                   | 602.05      | 0.0860              |</p>
<table>
<thead>
<tr>
<th>Mass (kg)</th>
<th>Component</th>
<th>Quantity</th>
<th>Material</th>
<th>Equipment</th>
<th>Attachment</th>
<th>Fuel Consumption (L/hr)</th>
<th>Fuel Type</th>
<th>Fuel Energy Content (MJ/L)</th>
<th>Machines</th>
<th>Labour</th>
<th>Hours</th>
<th>Productivity Factor</th>
<th>Energy (MJ)</th>
<th>Energy Int. (MJ/kg)</th>
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<td>Hammer</td>
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<td>Diesel</td>
<td>38.68</td>
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<td>1</td>
<td>5.11</td>
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<td>5593.6</td>
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**Concrete Stockpiling, Loading, Transportation to Offsite MRF (15" minus nominal size material)**

| 1542935 | Stockpiling 15" | 1543MT | Concrete | Cat 325L | Bucket | 25.2 | Diesel | 38.68 | 1 | 1 | 25.70 | 1 | 25051 | 0.0162 |
| 1542935 | Loading 15"     | 1543MT | Concrete | Cat 325L | Bucket | 25.2 | Diesel | 38.68 | 1 | 1 | 25.70 | 1 | 25051 | 0.0162 |
| 336000  | Excavate Footings | 280m³ | Soil         | Cat 325L  | Bucket     | 22.1 | Diesel | 38.68 | 1 | 1 | 7.00  | 1 | 5983.8 | 0.0178 |
| 1542935 | Transportation 15" | 1543MT | Concrete | Tridem    | Dump Trucks | 24.1 | Diesel | 38.68 | 1 | 1 | 6.72  | 1 | 5332.1 | 0.0035 |

**Subtotal**

| 1542935 | Float Trailer | | Equipment | Tractor | Trailer | 24.1 | Diesel | 38.68 | 1 | 1 | 10.00 | 1 | 9321.9 | N/A               |

**Steel Demolition/Recycle Off Site**

**Above Grade Horizontal - Primary Structural**

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<td>W360x33 roof</td>
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**Above Grade Horizontal - Secondary Structural**

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NOTES
Projected time frame to complete is 6 weeks
Concrete Topping Removal Crew - 2 compressors with 4 chipping hammers, 2 skid steer with operator plus labourer
Concrete Breaking and Removal - 2 Caterpillar 235L excavators plus attachments
Steel Demolition - 6,000 sq. ft./hour, Preparation 15MT/hour
Concrete Topping quantities includes stair tread fill
## Table B4: Steel Structure
### Baseline Reuse Case

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<th>Fuel Energy Content (MJ/L)</th>
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<th>Labour</th>
<th>Hours</th>
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**Subtotal**

| 1534732   |                      |          |            |            |            |                        |           |                             |          |        |       |                     |             |                     |

### Below Grade Vertical

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<th>Equipment</th>
<th>Attachment</th>
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<th>Fuel Type</th>
<th>Fuel Energy Content (MJ/L)</th>
<th>Machines</th>
<th>Labour</th>
<th>Hours</th>
<th>Productivity Factor</th>
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**Concrete Stockpiling, Preparation, Loading, Crushing onsite for reuse as clean fill (2.5" minus nominal size material)**

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**Subtotal**

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**Steel Dismantling/Reuse**

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<p>| 6937               | W360x33 roof | Steel         | Atlas Copco    | XAS 90 Comp. | 10.1                    | Diesel    | 38.68                       | 2        | 4      | 23.54 | 1                   | 18471       | 2.663              |
| 5148               | W410x39 roof | Steel         | Atlas Copco    | XAS 90 Comp. | 10.1                    | Diesel    | 38.68                       | 2        | 4      | 14.86 | 1                   | 11511       | 2.255              |
| 629                | C200x17     | Steel         | Atlas Copco    | XAS 90 Comp. | 10.1                    | Diesel    | 38.68                       | 2        | 4      | 4.16  | 1                   | 3250.4      | 5.168              |
| 14040              | W410x39 beams | Steel        | Atlas Copco    | XAS 90 Comp. | 10.1                    | Diesel    | 38.68                       | 2        | 4      | 40.50 | 1                   | 31644       | 2.254              |
| 15982              | W460x61 beams | Steel        | Atlas Copco    | XAS 90 Comp. | 10.1                    | Diesel    | 38.68                       | 2        | 4      | 29.48 | 1                   | 23034       | 1.441              |</p>
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<th>Equipment</th>
<th>Attachment</th>
<th>Fuel Consumption (L/hr)</th>
<th>Fuel Type</th>
<th>Fuel Energy Content (MJ/L)</th>
<th>Machines</th>
<th>Labour</th>
<th>Hours</th>
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**Above Grade Horizontal - Secondary Structural**

| 7045     | Roof Joists 450-18C | 757.5m | Steel    | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 4        | 56.81  | 1     | 44388               | 6.301        |
| 1363     | Cross Bridging L55  | 408.0m | Steel    | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 4        | 6.12   | 1     | 4781.8              | 3.506        |
| 25740    | Floor Joists 450-20D | 2475m  | Steel    | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 4        | 185.53 | 1     | 145039              | 5.635        |
| 3060     | Cross Bridging L55  | 916.0m | Steel    | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 4        | 12.24  | 1     | 9563.6              | 3.125        |
| 13628    | Main & Stair Roof   | 1584.67 m² | Steel Deck | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 8        | 11.89  | 1     | 9290.1              | 0.882        |
| 26778    | 2nd & 3rd Floors    | 3113.70 m² | Steel Deck | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 8        | 23.35  | 1     | 18244               | 0.681        |
|          | **Subtotal**        |          |          |            |            |                         |          |                          |          |        |       | 231307              | 2.090        |

**Above Grade - Vertical Columns**

<p>| 2756     | Roof Columns        | 153.6m  | Steel    | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 4        | 11.52  | 1     | 9001                | 3.219        |
| 4009     | 3rd Floor Columns   | 172.8m  | Steel    | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 4        | 12.96  | 1     | 10126               | 2.526        |
| 5772     | 2nd Floor Columns   | 172.8m  | Steel    | Atlas Copco XAS 90 Comp. | 10.1       | Diesel                  | 38.68    | 2                        | 4        | 12.96  | 1     | 10126               | 1.754        |</p>
<table>
<thead>
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**NOTES**

Projected time frame to complete is 10 weeks.
Concrete Topping Removal Crew - 2 compressors with 4 chipping hammers, 2 skid steer with operator plus labourer.
Concrete Breaking and Removal - 2 Caterpillar 235L excavators plus attachments.
Concrete Crushing - Production Rate of 80MT an hour.
Steel Dismantling - 2 crews of 4 personnel - 2 compressors with 4 air wrenches.
Column baseplates and anchor included in concrete operations.
Concrete topping includes stair tread fill.
# Table B5: Concrete Structure

## Baseline Recycle Case

### Concrete Breaking/Recycle Off Site

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*NOTES
Projected time frame to complete is 5 weeks
Concrete Breaking and Removal - 2 Caterpillar 325L excavators plus attachments
Concrete Demolition - Floorings, Columns - 5.2m³/hr; Walls-7.8m³/hr.; Slabs 228mm - 14.9m³/hr.; slabs 178mm - 17.92m³/hr.


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**Concrete Stockpiling, Preparation, Loading, Crushing onsite for reuse as clean fill (2.5" minus nominal size material) Totals**

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**Project Management**

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**NOTES**

Projected time frame to complete is 6.5 weeks
Concrete Breaking and Removal - 2 Caterpillar 235L excavators plus attachments
Concrete Demolition - Footings, Columns - 5.2m³/hr; Walls-7.8m³/hr; Slabs 228mm - 14.9m³/hr; slabs 178mm - 17.92m³/hr.
Concrete Crushing - Production Rate of 80MT an hour